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THE

OSTEOLOGY OF AMIA CALVA,

INCLUDING

CERTAIN SPECIAL REFERENCES TO THE SKELETON OF TELEOSTEANS.

BY

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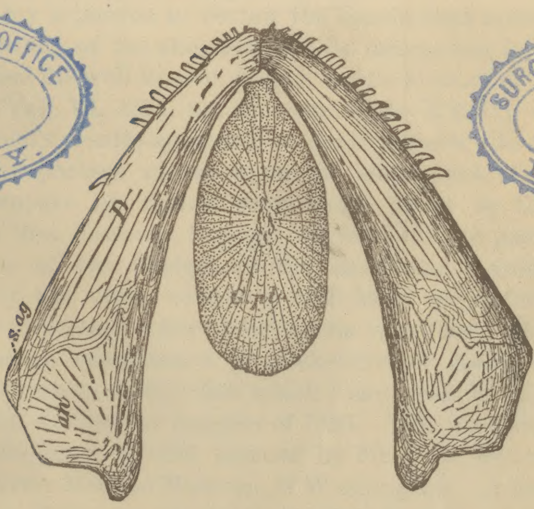

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000.—THE OSTEOLOGY OF AMIA CALVA: INCLUDING CERTAIN SPECIAL REFERENCES TO THE SKELETON OF TELEOSTEANS.

By R. W. SHUFELDT, M. D.,

Captain Medical Corps, U. S. Army.

The present paper will be divided into two parts; of these, Part I will consist of a translation of the admirable article of Dr. M. Sagemehl, entitled "*Beiträge zur vergleichenden Anatomie der Fische*," the first contribution given us being "I. *Das Cranium von Amia calva*, L." This carefully written essay appeared in the second part of the ninth volume of the *Morphologisches Jahrbuch*, for the year 1883. It is illustrated with one double-page, beautifully executed plate. The twelve figures in this plate I have had, through the kindness of Professor Baird, carefully copied by Mr. H. L. Todd, the artist of the Fish Commission and Smithsonian Institution. They appear in their proper places in the plates illustrating this article with their explanations set opposite to them.

In Part II it is my intention to review the conclusions arrived at by Bridge, after his study of the skeleton of this interesting form. This anatomist published his well known memoir in the Journal of Anatomy and Physiology (Vol. XI, 1877, pp. 605–622, Plate XXIII), six years before Dr. Sagemehl's results appeared in the *Jahrbuch*. In this part, too, I will bestow a passing glance upon the monograph of Henricus Franque,[1] and compare his figures with those given by the above authors. Beyond this, however, it is not my intention to pass further into the literature of the subject, as the short and unsatisfactory accounts given by the older writers would avail us nothing here. Finally, I propose to present a few observations of my own, which have been the result of an examination of a skeleton of *Amia*, carefully prepared from a specimen of this fish which I captured in the vicinity of New Orleans, La., during the summer of 1883. This preparation was done for me in the most skillful manner by Mr. J. L. Wortman, the anatomist of the Army Medical Museum, of Washington. A few figures will be presented in this part, illustrating points that do not appear in Dr. Sagemehl's article.

[1] *Amiæ Calvæ Anatomiam*, Berolini, 1847.

PART I.

Ever since 1845—when Carl Vogt[2] demonstrated that *Amia calva*, L. differed in the structure of its heart from all known bony fishes, being like the cartilaginous fishes in this respect; and since Johannes Müller,[3] noting this circumstance, separated this remarkable fish from the Clupeoids, with which it had formerly been classed, adding it to his and L. Agassiz's established sub-class of Ganoids—the attention of anatomists has been steadily directed towards this form.

A number of works touching upon nearly all parts of the anatomy of *Amia* have made their appearance, so its structure is at present better known than that of most bony fishes. It is quite remarkable that the cranial anatomy of this Ganoid has not received proper attention, as it is by no means a rare fish in collections. The memoir by Bridge,[4] published in 1877, is in my opinion the only one in which the subject has been at all fully described.

Upon the suggestion of Privy Counselor Professor Gegenbaur, I undertook the task of re-examining the crania of the Teleostei, especially in the Physostomi and the Anacanthini, and in looking for a form in which the various differences in the structure of the skull could best be judged, my attention was drawn to *Amia*. In fact, a careful study of the cranium of this fish showed that several diverging series of skull-types could easily be traced from it. On the other hand, the task of tracing the conditions of the cranium of the Teleostei from more simply constructed types—such as the Selachians offer—I found the *Amia* to be an excellent transitory form for the purpose. The careful descriptive work of Bridge, with whom I concur in the majority of points, so far as the actual conditions are concerned, does not suffice for this special purpose. Certain points of organization, which at the first glance appear to be incorrect, and the significance of which only become apparent after comparisons with other forms, he has left entirely unnoticed. Furthermore, in his descriptions he has kept strictly within the limits of his title, perhaps for lack of material, describing only the bones of the skull and entirely neglecting the surrounding soft parts, in which I recognize the necessary elements to complete the configuration of the skull. Finally, in my opinion, Bridge has not been fortunate in his descriptions of several of the bones of the skull in *Amia*.

Taking all this into consideration, I decided to present a comparative description of the skull of *Amia*. At the same time I believe I will be

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[2] *Annales des Sciences Naturelles*, T. IV, 1845. (I have changed the numbering of Dr. Sagemehl's foot-notes so as to accommodate them to the present article.—TRANS.)

[3] *Über den Bau und die Grenzen der Ganoiden. Abh. d. k. Akad. d. Wissenschaften z. Berlin vom Jahre* 1844. *Berlin*, 1846. *Nachschrift*, pag. 204.

[4] The Cranial Osteology of Amia calva. Journ. of Anatomy and Physiology, Vol. XI, 1877, pages 605–622.

able to discuss several questions of a more general nature, which are of prime importance when taken in connection with my work upon the crania of the Teleostei, soon to be undertaken. It only remains for me to justify myself for having confined myself in this work, as I will in those of the future, strictly to the cranium, and for having but touched lightly upon those parts of the visceral skeleton connected with it; and that, too, only so much of it as was necessary to complete the form of the skull. Such partiality would hardly be justifiable were one considering the forms the cranium assumes in the higher vertebrates.

This is entirely different in the class Pisces. The visceral skeleton here has, in so far as the cranium is concerned, preserved a certain independence, and in consequence its form has been much less influenced, less so than other organic systems, as for example the nervous system, the muscular system, and particularly the organs of sense.

There is yet another objection that might be brought forward, and that is, that I have paid but little attention to the literature of the subject, particularly the older literature. In my allusion to facts long known—and, as I assume, of facts well known—it seemed to me entirely superfluous to continually cite authorities. Such a course would have rendered my subject-matter diffuse and unwieldy, without adding anything useful. The literature relating to it, contained in the more recent and less known works, and which refers to the discussion of purely special points, I have in every instance conscientiously cited.

Through the unbounded liberality of Privy Counselor Mr. Gegenbaur, to whom I here express my profound thanks, I have been enabled to examine five specimens of *Amia*, the smallest of which was 36^{cm}, the largest 57^{cm} long.

In viewing an unprepared head of *Amia calva* one can already distinguish the superficial plates of bone that overlie the cranium, they being merely covered by an extremely thin cutis.[5]

The sculpturing of the superficies of these bony plates is quite characteristic, consisting of sharply-defined and numerous ridges, which start from the center of each bone, to radiate outwards to the peripheries. After the thin skin covering them has been carefully removed one recognizes the limits of the several bones with requisite distinctness. Three pairs of bony tables, situated one behind the other, first meet the eye, of which the foremost possesses the greatest and the hindmost the least longitudinal extension.

The foremost of these pairs of plates consists of two bones, each of a quadrilateral outline, being joined together mesially by a strong dentated suture. (Plate I, Fig. 1.) The lateral borders of these bones arch over

[5] If Bridge (*loc. cit.*, page 606) describes the surface of these bones as "highly polished," and further says "they are destitute of any covering of soft skin," he is in error. One can easily convince himself, from a microscopical examination, that all of these overlying plates of the skull in *Amia* are not only covered by an epidermis—which is also present is *Lepidosteus* and *Polypterus*—but undoubtedly also possesses a very thin covering of cutis.

the orbits, while their anterior lateral angles rest upon the antorbital processes. In view of this arrangement this pair of bones are characterized as the *frontalia*[6] [frontal plates].

Behind these two bones, follow two others of an approximately quadrilateral outline, which like the preceding pair are connected together in the middle line by a dentated suture. These are undoubtedly the *ossa parietalia* [parietal plates], which in *Amia*, as in several other bony fishes, are suturally united mesiad[7]. (Plate I, Fig. 1.)

On either side of the parietalia and of the posterior part of the frontalia is found a longitudinally placed bone (Plate I, Fig. 1, *Sq.*), which corresponds in all respects with the *os squamosum* of the Teleostei.[8]

Articulating with its hinder border with the squamosal on either side, and being situated at about the middle of the latter half of the frontal, we observe another osseous plate, with its long diameter placed longitudinally. It is the osseous plate that overlies the continuation of the post-orbital, and is the post-frontal (Plate I, Fig. 1, and Plate II, Figs. 5 and 6, *Psf.*). A similar, only smaller, bone-plate, extensively sculptured, articulates with the anterior lateral angle of the frontal, and is the superimposed plate that represents the prefrontal (Plate I, Figs. 1, 2, and 3, *Prf.*). While the bony plates just described are firmly articulated with one another, and are also in intimate relation with the true cranium beneath, or are even blended with it, the two rather small osseous plates (Plate I, Fig. 1, *Ex.*) situated behind the parietals and squamosals, and meeting each other in the middle line,[9] are connected only with the bones in front of them by means of dense ligamentous bands. Nor

[6]As regards the determinations of these bones, I have adhered strictly to the names used for them by Gegenbaur. It is of course universally known that these names, now long in use, do not express any homology whatever with the correspondingly named bones of the higher vertebrated animals. I am of the opinion that a complete homology exists for only a very few of the bones of fishes when compared with those of the higher vertebrata. There is not positive proof for a single one of them at the present writing. The most rational thing to do under the circumstances would be to introduce, if possible, a new and neutral nomenclature for the bones of the skull in fishes; yet I did not think myself justified in introducing such an innovation, which at any rate, so long as an exhaustive knowledge of the bones of the skull in fishes is not complete, could only be provisional, and I have therefore contented myself with the old names.

[7]Bridge, on whose specimen this mesial suture between the *Paritalia* had worn away, bestows, in consequence, upon the blended bony plates the name of "dermosupraoccipitale," a name which in any event is inadmissible. On seven specimens of *Amia*, examined by me for the special purpose of looking into this condition, I have invariably found the median suture to be present, agreeing in this particular with the descriptions given by Owen and Franque, and I must consider the condition as found by Bridge as an individual anomaly, to which no further significance need be attached.

[8]Bridge takes this pair of bones for the parietalia because they lie upon either side of his dermosupraoccipitale.

[9]If Bridge intends to convey the idea that these plates do not meet each other in the middle line, he is in error; his own drawing (Plate XXIII, Fig. 1) proves to the contrary.

have they anything whatever to do with the primoidal-cranium, and they are even separated from the exoccipitals by connective tissues, though they overlap these bones to some extent. The greater part of one of these bones laps over one of the bones of the shoulder girdle, which latter rests with a mesially-directed process upon the hinder border of the exoccipital, while its remaining process, directed forwards, is attached by a strong ligament to the intercalare. This bone (Plate I, Fig. 1, *Sc.*) corresponds in all respects with the suprascapula[10] found in nearly all of the Teleostei.

Among the Teleosteans one quite constantly finds, between the processes of the suprascapula, a very superficially-situated dermal bone, which was first differentiated by Stannius from the supratemporal bone, which articulates laterally with the squamosal, and has been termed the extrascapula. This bone usually is not very large, yet in a few cases, as for example in *Macrodon*, it attains quite a considerable size; it then resembles in a great measure the bone as just described for *Amia*, and it is only to be distinguished from it in that it does not meet its fellow in the middle line. One will therefore hardly go astray in regarding the bone in *Amia*, designated in Plate I, Fig. 1, as *Esc.*, as homologous with the extrascapula of the bony fishes.

The nasal region of *Amia* is covered by five small dermal bones, which are separated posteriorly from the frontal plates by a small tra. sverse strip of cutis.

The dermal bone (Plate I, Fig. 1, *Eth.*), placed most anteriorly of this group, has the form of an equilateral triangle, with the apex directed backward, and with a somewhat spreading base. It lies more deeply seated in the skin than the rest of these bones that overlie the cranium, but nevertheless it shows traces of the sculpturing that characterizes them all. Posteriorly, and to either side of this unpaired osseous plate, lie a couple of small bones (Plate I, Fig. 1, *Na.*) of which the two medial ones are somewhat the larger pair. These are separated anteriorly by the azygos bone, just referred to, penetrating between them; behind, they meet each other in the median line. On either side of these dermal bones lie two smaller ones (Plate I, Fig. 1, *An.*), of which no special notice need be taken. The four bones just described, more especially the medial pair, form the covering to the nasal cavity. Among the three bones designated by *Eth.*, *Na.*, and *An.* there remains, where they come together anteriorly, a small opening which leads to the rhinal chamber, and corresponds to the anterior nasal aperture of *Amia*. The posterior nasal opening is far removed from the anterior, being situated at the posterior lateral angle of the bone designated by *Na.* The interpretation of the dermal plates just described is not difficult.

The two posterior medial dermo-bones, holding, as they do, a position in front of the frontals and above the narial depressions, correspond or answer to the nasal bones of osseous fishes. There is yet another con-

[10] Suprascapula of Cuvier; omolita of Geoffroy and Stannius.

dition of these bones that supports this statement, viz, their relation to the mucus canals of the head.[11]

Among the Teleostei the anterior branch of the mucus canal, imbedded in the frontal bone, begins with an opening which is situated to the inside of the anterior nasal aperture. Its course in the nasal is backwards, and then it passes through the frontal, in which it throws off several side branches.

This portion of the mucus canal bears exactly the same relations to the bones in question in *Amia* as in the nasal among the Teleosteans, as may be seen by referring to Plate I, Fig. 1.

The mucus canals can also be utilized in defining both lateral bones. The main branch of the mucus canal, imbedded in the same, unites with the canal of the suborbital arch, and only a small lateral branch anastomoses with the mucus canal of the frontal. This condition reveals the fact that the bone just mentioned must be the first piece of the suborbital arch somewhat removed from its usual position—the antorbital.

The middle non-parial piece can also be determined without difficulty. In it we see a rudimentary ethmoid which has abandoned its customary site and relations with the frontalia, owing to the unusually developed nasal bones. So Bridge has likewise considered it; in fact, one could hardly regard it in any other light, unless choosing the very improbable assumption that the ethmoid—very constant elsewhere—is entirely absent in *Amia*, and that this fish is provided with a peculiar prenasal bone that never occurs in other fishes. Our determination is undoubtedly correct, as we find in *Polypterus* an identically similar bone, though here it is connected with two small processes of the frontalia that enter in between the nasals.[12]

All of the bones just described that overlie the cranium, with the single exception of the prefrontal, are pierced by a system of mucus canals, which are worthy of a closer consideration (see Plate I, Fig. 1).

As already mentioned above, a large mucus canal commences, mesiad, by the anterior nasal aperture to follow a course first in the nasal, then through the entire length of the corresponding frontal, to terminate in the extreme anterior portion of the parietal, on the surface of which its mouth is to be found.

The right and left canal are connected anteriorly by means of a transverse anastomosis which passes through the ethmoid. During its course through the posterior part of the frontal the mucus canal just described throws off a lateral branch, which passes through the postfrontal, and, being confined between the bones of the orbital arch, passes around the

[11] I desire to mention, at this point, that hitherto the relation of the mucus canals to the bones of the cranium have hardly been given a thought, and yet they deserve a closer study, as these relations are very constant, and in questionable cases they can be used to determine doubtful homologies.

[12] Cf. the representation of Müller, Structure and Limits (*Grenzen*) of the Ganoids, Pl. I, Fig. 1.

eye, reaches the preorbital, and terminates laterally near the anterior nasal aperture.

From the mucus canal leading to the orbital arch another canal takes origin, beginning in the frontal, passing through the entire length of the squamosal, to enter the extrascapula and suprascapula. After passing through the suprascapula it becomes the mucus canal of the lateral line, passing on to terminate at the tail. Both of these canals, just referred to, are united by a transverse anastomosis, which is imbedded in the substance of the extrascapula. During its course through the squamosal a branch directed laterally arises from this canal. This branch enters the preoperculum, passing through the entire length of this bone to enter the mandible beyond, and eventually join the fellow of the opposite side, which it meets at the symphysis. All these mucus canals send off numerous ramifications of smaller canals, arranged in several longitudinal rows, which terminate on the surface of the head in minute openings.

Taking into consideration their superficial location, the peculiar sculpturing of their surface, and the possession of mucus canals, the bones we have just described are unquestionably characterized as ossifications of the skin—as dermal bones. In making any attempt to remove these dermo-bones one recognizes the fact that their relations to the chondrocranium are very different.

The ethmoid, the nasals, and the preorbitals[13] do not come in contact at all with the same, but are separated from it throughout their entire extent by soft parts.

On a microscopical examination of cross-sections made from one of these bones (take for example the extrascapula) one can distinguish a superficial layer from a deep one. The latter consists of osseous lamellæ, which are piled up parallel with the bony plane, and which are interrupted by others, arranged concentrically around the Haversian canals.

This deeper bony layer gives passage to quite a number of capacious Haversian canals and is supplied pretty generously with bone corpuscles. The superficial layer of these dermal bones is characterized, when compared with the one just described, by a much denser tissue, by a small number of Haversian canals, by an almost entire absence of bone corpuscles, and, what is most important, by the existence of numerous and very minute dentine tubelets (*Dentinröhrchen*) which penetrate it from the surface of the bone. Yet I wish to explicitly state that one cannot make out the exact boundary between these two layers with any certainty.

The frontals, parietals, and squamosals are in more intimate relation with the skull. In part, these are quite closely connected with the cartilaginous cranium, and are separated from it simply by a layer of thin connective tissue. Histologically they remind one very much of the

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[13] This applies also to the extrascapular, the suprascapular, and the supraclaviculas.

bones of the first group. The two osseous layers can also be distinguished in them, but the inferior one is better developed and more plentifully supplied with Haversian canals, so that it becomes quite spongy in character. As already stated, they are separated from the underlying cartilage by a thin layer of connective tissue, through which ramify a numerous set of vessels, and in which are found pigment cells.

Finally, the postfrontals and prefrontals present us true "primary" ossifications of the primoidal cranium, which cannot be removed without injury to it, and which only remind us of their original development as dermal bones by their superficial location and by their sculptured surfaces, the former also by their having mucus canals.

The conclusion which we arrive at after our examination of these two bones in *Amia*, and which they afford, is so unique and so unlike the usual conditions that characterize those specific differences between dermal bones and the ordinary ossifications of the true skeleton, that it is easily perceived how Bridge was induced to separate each of these bones into two components, and to distinguish the true—corresponding to the homologous bones of the Teleostei—prefrontal and postfrontal, as well as the "dermoprefrontal and dermopostfrontal," covering the same. An unprejudiced examination at once convinces us that the conclusions arrived at by Bridge do not agree with the actual condition of things. The plates of these bones, visible on the surface of the cranium, as well as the outer layer of all the other dermal bones, undoubtedly consist of a compact and very hard bony substance, while those parts which are more deeply situated are more cancellous in texture; still the transition of one to the other is gradual, and the superior plate cannot be removed without breaking the bone.

Here a rare case presents itself—up to the present time almost universally doubted—in which bones that on their surface present all the characteristics of dermal bones have acquired relations with the true skeleton through their more deeply situated parts or structure, and in consequence are in part dermal and in part true bones.

Another group of bones is to be seen—partly, also, without dissection—from the cavity of the mouth. Lying in the median line and longitudinally placed upon and belonging to the parasphenoid is an osseous strip that is entirely covered over with a growth of firmly implanted and small conical teeth.[14] Between these teeth the bone is covered by a very thin layer of mucous membrane, which is only to be discovered after careful search.

Situated anterior to these median bony strips, there is on either side a number (from 17 to 22) of strong conical teeth, which are supported by the vomer. As the interstices among these teeth are filled in by a thick mucous membrane, nothing can be seen of the bones from an

[14] When Bridge speaks of roughness (asperities) of the parasphenoid, he does not convey to us the correct idea or condition. This roughness is caused by these true teeth, and of this fact Franque was already cognizant.

external view. Similar bone-plates, provided with fine little teeth, such as those just described for the parasphenoid, are found upon the palatine, upon the three pterygoids, and upon the splenial of the mandible. After the excellent investigations of Leydig[15] and O. Hertwig[16] a particular reason is hardly required if I place the parasphenoid and the vomer, as ossifications of the mucous membrane of the mouth, opposite the dermal ossifications and the true ossifications of the skull.

In respect to this, it seems to me that the condition found to exist in *Polypterus* is of peculiar significance; in this form, according to Leydig's investigations, all the bones of the buccal cavity are covered over by the epithelial layer solely. The *Amia*, where the ossifications beneath the epithelium are likewise covered by a layer of connective tissue, constitutes an excellent example, so far as this condition is concerned, of the transition stage between this form and the majority of bony fishes, in which the parasphenoid and vomer are hidden beneath the thick mucous membrane of the mouth.

After the cranium has been skeletonized, the parasphenoid and the parial vomer can be easily discerned.

The *parasphenoid* (Plate I, Fig. 2, *ps.*) is a flat bone, having the form of a cross. Its stem extends from the hindermost extremity of the skull to the antorbital, and very near its middle it gives off two branches, which extend laterally and upward alongside the postorbital, and form the posterior boundary of the orbit.

The posterior extremity of the parasphenoid is deeply cleft, thus allowing a small triangular portion of the basi cranii, represented by the basioccipital, to come into view upon a basal aspect of the skull. That part of the bone which is provided with teeth, and which in different individuals varies with regard to its anterior and posterior extension, lies mesially between the two branches.

In front of the parasphenoid are found the two *vomers* (Plate I, Fig. 2, *vo.*), articulating with each other in the middle line. They are flat osseous plates, placed longitudinally, with their anterior thirds armed with stout teeth. Their posterior moiety covers the anterior part of the inferior aspect of the parasphenoid.

If the statement that the parasphenoid originally bore teeth over its entire surface be correct—and so many facts have been adduced in its favor that its correctness can hardly be doubted—the overlapping of the vomer on this bone must be a primitive state of affairs. In fact, if one compares this condition of *Amia*, with its parial vomer, with the arrangement in bony fishes, where the vomer is known to be always nonparial, hardly a doubt but that *Amia* represents the primitive condition remains.

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[15] W. Leydig, *Beitrag z. mikroskop. Anatomie v. Polypterus. Zeitschr. für wiss Zool.*, Bd. V.

[16] O. Hertwig, *Das Zahnsystem der Amphibien f. mikroskop. Anatomie.* Bd. XI, suppl.

Leaving entirely out of consideration the arguments that can be adduced in favor of a progressive development of *Amia* in the direction of the bony fishes, and that the division of a bone into several parts is an hypothetical process, the positive proof has been given us by Walther [17] that the vomer of the pike is a parial ossification. Yet the present position of the vomers in *Amia* is not the primitive one, and in order to get around all difficulties involved in this question we must assume that in still more pristine forms both these bones occupied a position more remote from the mesial line, on either side of the anterior extremity of the parasphenoid, as in many existing Amphibia.

The conclusion arrived at from these inferences—taken in connection with the fact that the vomerine and palatine teeth of fishes are situated in one and the same line, lying in the same arch—gives some coloring to the supposition that the vomers of fishes originally constituted the anterior overlapping segments of the palatine arch, as has been proven by Hertwig for the Amphibia.

To the "cover-bones" of the skull in *Amia* yet belongs another piece, that with other forms is not so intimately related to the primodal cranium. It is the *intermaxilla* (Plate I, Fig. 1, and Plate II, Fig. 6, *Sm.*).

This is to be seen extended upon the cartilaginous base of the rhinal chamber, proceeding backwards from its arched and compact alveolar process; this thin osseous plate encroaches to no small extent upon the antorbital region.

In the posterior portion of the nasal depression this plate is pierced by a large foramen for the passage of the olfactory nerve (Plate I, Fig. 1, *ol.*).

The integrity of the cartilaginous cover of the primoidal cranium of *Amia* is thoroughly preserved throughout, being devoid of fenestræ or other breaches in its substance of any kind whatever.

In outline it resembles a triangle placed longitudinally, with its apex cropped off anteriorly; it is generally level, and marked only by pit-like impressions at the posterior lateral angles, and by a number of projecting processes, which are more or less ossified. The two anterior ones are the antorbital processes (Plate I, Fig. 1), with their ossifications already described—the prefrontals. At about the middle of the skull-cover the postorbital processes project out laterally at each side, together with their ossifications, also described as the postfrontals (Plate I, Fig. 1).

The prominent posterior lateral angle of the primoidal skull is occupied by the intercalare [opisthotic] (Plate I, Fig. 1, *Jc.*).

As we proceed towards the median line from the angle formed by the intercalare we find rising on either side another process, situated not quite so far behind, that is formed by the exoccipital (Plate I, Fig. 1, *Ex.*). Between these processes, formed by the intercalare and exoccipital, ex-

[17] J. Walther, *Die Entwicklung der Deckkurcken am Kopfskelet des Hechtes. Jenaische Zeitschrift f. Naturwiss.*, Bd. XVI, 1882.

tensive fossæ are found on the skull, that extend well anteriorly towards the frontal region (Fig. 1).

As the dermal bones, occupying their respective places, the squamosal and lateral margin of the parietal span this depression as the arch of a bridge, it gives rise to a cavity between the primoidal cranium and its cover-bone, the opening of which is upon the posterior aspect (Plate II, Fig. 6, *tg.*[18]) and into it enters, to be attached to the occiput on either side, a part of the muscle of the dorsum of the trunk.

This depression, which forms so striking a feature of the skulls in the Teleostei, I here propose to name the temporal fossa.[19]

Projecting from the middle line posteriorly there is a short cartilaginous process (Fig. 3, *Oc.*[20]) that occupies precisely the same position that the superoccipital does in the Teleostei. The last-mentioned bone is wanting in the Siluroids and Dipnoi. From the hinder boundary of the vault of the skull it is produced downwards and backwards, and finally is drawn out as a cylindrical prolongation of the same, in which is contained the posterior part of the medulla oblongata and the anterior commencement of the spinal cord.

The occipital region[21] of *Amia* is, so far as a comparison with bony fishes teaches us, remarkably drawn out longitudinally, and this prolongation, the cause and significance of which will be discussed further on, concerns chiefly the region posterior to the foramen for the vagus.

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[18] This is given in the text of the original as *Th.* and I here correct it to *tg.*—Trans.

[19] This point is the proper one for us to take a careful look into the relations of the squamosal to the primoidal cranium. This bone rests by its lateral border only upon that crest of the primoidal skull which is directed upwards and outwards and forms the lateral boundary of the temporal fossa. Now, although the squamosal in *Amia*, as already stated, is a dermal bone, which appears only to be resting upon the primoidal cranium, it would be impossible to remove it without injury. This is the site it occupies: from the lateral margin of the bone are developed two osseous ridges, which are directed downwards and to some extent towards the median line, and have, when articulated, the two corresponding sharp cartilaginous crests of the skull inserted between them. The lateral ridge of the squamosal, of the two mentioned ones, is juxtaopposed to the lateral surface of the skull, and is carried from the margin of the bone downwards to the hyomandibular articulation. The remaining or mesial ridge lies in the temporal fossa. This condition is significant in so far that among the Teleostei it is only through the lateral margin of the squamosal, that the cartilages are wedged apart, and the firm union of the bone with the primoidal cranium takes place.

[20] This is *Co.* in the original text, and it has been corrected here to *Oc.* In either event it is not quite clear what Dr. Sagemehl intends to indicate, so *Oc.* has been omitted from my letters of reference, as I must believe he refers to *Ol.*—Trans.

[21] It appears to me more to the point to consider the foramen for the glossopharyngeal and the posterior border of the petrosal as the extreme anterior boundary of the occipital region in the bony Ganoids and Teleostei, and not the foramen for the vagus, as Gegenbaur has done for the Selachians. In the fishes examined by us these two nerves are intimately related to each other, and in rare cases they may even have a common foramen of exit, so that placing them in this or that region would be quite arbitrary. Moreover, in the limitation proposed by me the confines of regions are almost without exception defined by the sutures between the bones, and therefore it becomes unnecessary to award a bone to different regions.

The base of the occiput is occupied by the *basioccipital* (Plate I, Figs. 2 and 3; Plate II, Figs. 4 and 5, *Ob.*). This bone has the form of a mussel-shell, not unlike *Cardium* or *Pecten*. Posteriorly it is shaped like the centrum of a vertebra, and presents for examination a tolerably even and conical excavation, into which the anterior end of the chorda enters. The margin of this excavation is connected by stout ligamentous bands to the centrum of the first vertebra, the anterior side of which appears slightly convex. Articulating with the lateral margins of the basioccipital are the *exoccipitals* (Plate I, Figs. 1 and 3 *Ol.*). These two bones, for the greater part of the posterior aspect of the primoidal cranium, assist in the formation of the lateral region only to a small extent. In large specimens of *Amia calva* they join together in the middle line over the medulla oblongata by means of a suture; in immature specimens they are separated throughout their entire extent by a strip of cartilage. They form no part of the articulation of the neural arch of the first vertebra, but they are separated from it by two bony arches, which rise upon the posterior portion of the basioccipital, having the form of a vertebral centrum, and which correspond in every respect with the neural arch of the vertebra, and shall be termed the occipital arches (Plate II, Figs. 4, 5, and 6, *Oc.* I and *Oc.* II).[22]

The anterior occipital arch is formed by two triangular osseous platelets, meeting together over the spinal cord, above which a non-paired oblong bone, directed upwards and backwards, is fastened by ligaments.[23]

The posterior arch is similarly fashioned, only both of its parts are of an oblong quadrangular shape, and develop on their posterior aspect a small articular facet for the arch of the first vertebra. Upon this arch is found also a pointed bone, directed upwards and backwards.[24]

The pointed bones resting upon the occipital arch are to be considered as spinal processes. At the same time, however, I will remark that inasmuch as they are situated in a line with the uppermost interspinous bones, which, indeed, no longer support the fins, one can just as well count them in with the latter. The boundaries between the fin-rays and the interspinous bones in *Amia* are not strictly defined, and the arrangement or condition they present us with in this form furnishes another proof that these formations originally had a genetic connection with each other. A good drawing of these conditions has been furnished us by Franque in Fig. 2 of his familiar treatise.

The occipital arches of Amia are not of uncommon occurrence, but are generally present either as independent arches, or reduced in various ways, or at-

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[22] Reads *obg.* in original text.—TRANS.

[23] So I find the condition in the older specimens. In the younger individuals, from which the illustration is taken, each half of the occipital arch consists of three separate osseous portions—one lower triangular piece, and two upper ones resting upon it and situated behind one another. It is not possible to find an explanation for this state of things at present.

[24] In the older specimens of *Amia* the two pointed bones are blended into one osseous plate.

tached to the hinder extremity of the skull, as in the higher fishes which are provided with ossified skulls.

In *Polypterus* a free occipital arch has been described by Traquair. Franque has also observed the occipital arches of *Amia*, as would appear from his brief and not entirely lucid description, but their significance appears to have entirely escaped him. Bridge mentions them also. Here and there other authors have noticed them, without having, up to the present time, placed any weight upon the occurrence of precisely the same thing in bony fishes. I have been able also to convince myself that the occipital arch is not wanting in *Leptidosteus.* In this Sauroid I find both halves synosteologically joined together, as well as with the basioccipital, so that this latter bone appears to form by itself the periphery of the occipital foramen. Among the osseous fishes one finds in the pike free occipital arches beautifully developed, also in the Salmonidæ and Clupeidæ; but, as shall now be particularly mentioned, proof can be furnished that all Teleostei originally possessed occipital arches.

Over the occipitale laterale, and connected with it at one small point, is found the conical exoccipital (Plate I, Fig. 1, *Ex.*). It constitutes the boundary to the entrance of the temporal fossa, mesiad, and is partly covered on its superior surface by the posterior margin of the parietal.

The posterior lateral angle of the primoidal cranium is occupied by a thoroughly developed bone, which I, in concurrence with Bridge, can only take to be the intercalare (opisthotic) (Plate I, Figs. 1, 2, and 3, *Jc.*). It is also a conical bone, which is covered above by the posterior lateral angle of the squamosum, and which helps to form the lateral boundary of the entrance to the temporal fossa. It does not articulate with the exoccipital, but remains separated from it by a strip of cartilage lying at the base of the temporal fossa. Posteriorly and beneath it comes in contact with the occipitale laterale, and in some individuals also with the basioccipital. Below and anteriorly, the intercalare, though a very delicate process, meets and unites with a process from the petrosal. To the apex of this bone, chiefly projecting posteriorly, the inferior limb of the supraclavicular is attached, as already shown, by means of firm ligaments. Below, the intercalare meets with the cartilage of the primoidal cranium, at which point something of a protuberance is developed.

It is known that in most osseous fishes the intercalare is wanting, and in the minority, where it still exists, it is feebly developed, with the exception of the family Gadidæ.[25]

Yet a comparison of the condition in *Amia* with that of the *Gadidæ* leaves not a shadow of a doubt that the bone just described is really the intercalare, inasmuch as this very bone in the Gadidæ possesses

[25] Compare the careful description of the intercalare of the Gadidæ by Vrolick, "*Studien über die Verknöcherung und die Knochen des Schädels der Teleostei.*" *Niederländ. Archiv. f. Zoologie*, Bd. I, 1873.

precisely the same topographical relations to neighboring ossifications of the skull, to the suprascapula, and to the foramen for the exit of the vagus and the glossopharyngeal.

The nerve situated most anteriorly in the occipital region is the glossopharyngeal. Its foramen of exit is found where the intercalare, the petrosal, and the cartilaginous portion of the primoidal cranium come together, and below and between the basioccipital and petrosal (Plate I, Figs. 2 and 3, *gph.*). Immediately after its exit from the foramen the glossopharyngeal divides into its two well-known branches, the distribution of which is of no interest in the present connection.

Thoroughly separated from the glossopharyngeal foramen we find the foramen for the vagus is so located in the suture between the intercalare and the occipitale laterale that its periphery is formed by these two bones (Plate I, Figs. 2 and 3, *v.*[26]). The nerve itself exhibits essentially the same behavior after its exit as in the *Teleostei.*

While yet within the brain-case the vagus gives off a very minute branch, which, ascending upwards, perforates the cartilaginous skull-cover beneath the parietal, into which it enters, probably to supply its mucus canal. I should not have mentioned this little branch at all if the so-called *ramus lateralis nervi trigemini*, which is known to receive fibers from the trigeminus and from the vagus, did not quit the cranium at the same locality in many of the Teleostei. That this nerve in *Amia* also receives fibers through its anastomosis with cranial nerves that arise more anteriorly I have once been able to confirm, but, in consequence of the indifferent manner in which the specimen I examined had been preserved, it was impossible to ascertain from which nerve this anastomosis proceeded. While the occipital region of the Selachians[27] arrives at its posterior limits with the vagus, in fishes provided with ossified skulls several nerves of the occipital group, and of a character identical with the spinal nerves, are constantly to be found between the vagus and the first spinal nerve.

Amia, possessing the largest number hitherto observed of occipital nerves, furnishes us with three such for our consideration. The most anterior of these leaves the brain-case at a minute foramen in the occipitale laterale, and situated near its posterior border (Plate II, Fig. 4, *oc* I). It is of a smaller caliber than the two following, and also differs from them in that it only arises from the spinal cord by means of an anterior root. The nerve next in order arises by both an anterior and posterior root, between the hinder border of the occipitale laterale and the anterior occipital arch (Plate II, Fig. 5, *oc* II). Immediately after their exit these two roots unite in a common trunk, and in so doing carry out the character of a spinal nerve (Plate II, Fig. 5, *oc* III). The first spinal nerve in *Amia* quits the neural canal between the posterior occi-

[26] Marked *vg.* in original text.—TRANS.

[27] As a matter of course only such Selachians are here taken into consideration whose crania are sharply defined from the vertebral column.

pital arch and the neural arch of the first vertebra, presenting us with nothing of particular note.

The three occipital nerves, together forming a group, run downwards in front of the shoulder-girdle, to finally ramify, and—probably together with the branch of the first spinal nerve, agreeing in this respect with the corresponding nerves in the Teleostei—to supply the muscles lying between the shoulder-girdle and the mandible. This I could not establish with certainty, for the reason that the specimen used by me for the examination of the nerves had already served for a dissection of the heart and great vessels. To complete the subject, a canal must yet be mentioned, the function of which I have been absolutely unable to discover. It commences on the lateral aspect of the bassioccipital, and on that portion of this bone which so much resembles a vertebra; it takes a course towards the median plane, turns at a right angle, and terminates at the inferior surface of the bone, between the posterior wings of the parasphenoid. This terminal opening is in close juxtaposition with the same opening of the canal of the opposite side, but no communication exists between them nor with the cavum cranii. The contents of this canal I found to be fibrous connective tissue and thin-walled vessels of some caliber (Plate I, Figs. 2 and 3, *cb.*).

The fact that free and independent neural arches are found upon the basioccipital, from between which emerge nerves of a structure like true spinal nerves, is of fundamental importance in the determination of skulls of the higher fishes, and admits of no other explanation than that which applies to the primoidal cranium, the best example of which we find in the Selachians, where we observe anchylosed together a still greater number of vertebræ, with the nerves that pertain to them making their proper exits.

A question still more difficult of determination is to define the number of vertebræ that enter into the composition of the cranium. In *Amia*, which for this purpose—of all the fishes with osseous skulls examined by me—possesses the best example of this primitive condition, I believe I am enabled to recognize the elements of three vertebræ. That the two occipital arches, with the nerves that pertain to them, represent the remains of what were originally distinct vertebræ, no reasonable doubt can exist; and the only question is whether we are to consider the first occipital nerve, which is very feebly developed and without a posterior [dorsal] root, as a rudimentary spinal nerve, or whether another interpretation is admissible.

If the first occipital nerve is not to be considered as a rudimentary spinal nerve, one can see in it—since it is absolutely inconceivable to have a generation of new nerves in the higher animals—but a branch of one of the two neighboring nerves, namely, of the vagus or of the second occipital nerve, that has branched and become independent. Now, the distribution of the first occipital nerve is such, that one cannot for an instant take it to be a branch of the vagus at all, and therefore the only possibility remains that it could belong to the second occipital

nerve. Such a thing as the branches of nerves eventually becoming new and independent nerves does occur in fishes, and I would invite attention to the condition seen in the spinal nerves in the Gadidæ,[28] and to the condition seen in the *ramus palatinus nervi facialis* in many bony fishes. There are two factors to be taken into consideration that enter into such a divisional process. The first of these is that distal regions supplied by the nerve may grow apart, and become further and further separated from each other; and the second is, that the tendency of each nerve is to take a direct course to the part it supplies. Both of these conditions would eventually bring about a division of a nerve to its very origin. Therefore this division must begin at the distal end of the nerve, and, gradually progressing, must extend finally to the point of origin in the central nervous system.

Precisely the opposite condition is found in the first occipital nerve; distally it is united with the second occipital nerve, it being but partially separated from it. Therefore the only justifiable conclusion we have left us to adopt is that this nerve must be considered as a discrete spinal nerve, the survivor of a retrogressive process, and so in *Amia* we must assume that at least three vertebræ have merged into the cranium.

I have yet to invite more careful attention to a condition not remarked upon by me before. Upon closer scrutiny of the occipitale laterale one sees that the hindermost part of this bone, where it meets the anterior occipital arch, is thickened and consequently well defined from the other bones. The anterior border of this thickened strip is in immediate relation with the minute foramen of exit of the first occipital nerve, and consequently this thickened portion of the bone exactly corresponds in form as well as in its site to a third anterior semi-occipital arch that has merged into the occipitalia lateralia. Now that the proof has been furnished that vertebræ, originally separate, have blended with the skull, an explanation can be given for certain points for examination that are to be found upon the inferior aspect of the basioccipital, which have not been alluded to by me before, because their significance would not have been understood.

Between the two posterior limbs of the parasphenoid, immediately behind the two lower exits of the vascular canals described above, that pass through the basioccipital, one finds two small pieces of cartilage, quite superficially placed upon the surface of the bone. (Plate I, Fig. 2, *x*.) On viewing the vertebral column of this fish from beneath, one can satisfy himself that very similar pieces of cartilage are upon each vertebral centrum; indeed, in younger individuals these cartilages penetrate deeply into the substance of the centra, while in the older specimens only very thin cartilaginous pieces can be recognized resting superficially on the vertebræ.

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[28] Stannius, *Das peripherische Nervensystem der Fische*, pag. 119.

Without going any further into an explanation of these cartilaginous formations, which could only be done by a careful comparison of the vertebral column of *Amia* with that of other fishes, I feel called upon to invite attention to the remarkable—even in details—similarity of the posterior portion of the basioccipital to the centrum of a vertebra.

To make a comprehensive statement, the occiput of *Amia calva* reveals the elements of three vertebræ, which are co-ossified with it, and whose individual independence becomes less and less marked from behind forwards. The centrum of the hindmost vertebra, as well as the centra of the other two, is co-ossified with the basioccipital; it is, however, only in the posterior portion of this bone that the evident likeness to the centrum of a vertebra can be recognized. The neural arch of this vertebra cannot be distinguished from the neural arch of a trunk-vertebra, and it possesses also a well-formed spinous process; the corresponding nerve is stamped with all the characteristics of a typical spinal nerve. The middle vertebra, absorbed as it is by the cranium, is quite similarly formed, only that its neural arch has become broader and intimately blended with the cranium. The transformation and co-ossification of the anterior vertebra is the most complete. Both halves of its neural arch are blended with the occipitalia lateralia, and the nerve corresponding to it arises simply as a feeble anterior root [ventral]. This rudimentary nerve is really the only safe indication of the existence of this anterior vertebra, which has in other respects been completely appropriated by the skull; and should one imagine that this nerve was formed through a retrogressive process, or became blended with the occipital nerve, then nothing would remain to give us the slightest hint as to the original existence of this anterior vertebra. This is of importance in so far as it gives rise to the possibility that beyond this vertebra, the existence of which is still to be seen through its last faint traces, there existed other ones, which, however, have become thoroughly appropriated by the cranium so as not to be any longer distinguishable.

The number which I have indicated, then—that of three vertebræ co-ossified with the skull—can therefore only be the fewest of these segments to be recognized. The view that the original number of these vertebræ was greater is by no means to be precluded.

It is hardly worth while mentioning that the facts just discussed by me have nothing whatever to do with the question of the composition of the primoidal cranium out of like constituents—the so-called vertebral theory of the skull. The formation of the primoidal cranium in the Selachii—and maybe, too, in the Cyclostomata—has already been perfectly defined; and setting the question entirely aside as to whether any or how many metameres were contained in those skulls, my only aim was to establish that between the Selachian skull and that of the higher fishes no complete homology exists. The cranium of the higher fishes corresponds to the cranium of the Selachii, plus several (at least three) of the anterior vertebræ of the column.

I would also expressly state that the proof just given only applies to the higher fishes, and that every attempt to assume the same condition for the higher organized vertebrate animals also must be premature at least. I would not have mentioned this particularly if attempts had not been made recently to show that the atlas of the Amniota is co-ossified with the cranium in Amphibia.

Stöhr[29] first made the interesting discovery that the so-called odontoid process of the Amphibia is nothing more than the notochord becoming cartilaginous, and subsequently developing as an ossified process from the first vertebra. Upon this discovery[30] Wiedersheim has made the assertion, for which there is no foundation, that the atlas of the Amniota is to be looked for in the occipital part of the skull of the Amphibia, and that in consequence of this the first vertebra in these forms corresponds to the axis.

After considering that the arrangement of the nerves in the occipital region, and of the first spinal nerves in the Selachians and Amphibia, at least in the Urodela, is identical; that in both, the vagus is the last nerve given off by the brain; further, that the entire occipital region in the Amphibia appears extraordinarily rudimentary, weighty reasons arose in my mind discrediting the idea that we find in the Amphibia the skull appropriating one of the vertebra, and I rather believed that a complete homology of the skulls in the Amphibia and Selachians must be accepted. Wiederscheim's view has its origin in the one-sided comparison of the conditions of organization in the Amphibia with that in the Amniota. Existing Amphibia, so far as their crania go, form a very restricted group by themselves, their structure permitting certain comparisons to be made down the scale toward the Dipnoi and Selachians, but not upward toward the Amniota. Consequently, if one foregoes a direct comparison of the skull of the Amphibia with that of the Amniota, a phylogenetic interpretation of the ontogenetic facts discovered by Stöhr would not be difficult. In all fishes, particularly the Selachians, a conically-pointed piece of the chorda extends into the occipital region of the skull, and one need only imagine that this notochord be transformed to cartilage, and afterwards—developed from the first vertebra—to ossify, in order to arrive at exactly the same conditions as they exist in Amphibia.

Then, to be sure, the odontoid process of the Amphibia is not homologous with the structure bearing the same name in the Amniota, but only presents an analogous formation; yet the supposition of homology even does not seem to me at all probable, inasmuch as it can be easily shown

[29] Ph. Stöhr, History of the Development of the Skulls of Urodela. *Zeitschrift f. wiss. Zoolog.*, Bd. 33. 1880.

[30] Wiederscheim, Comparative Anatomy of the Vertebrate Animals, page 60. It is not uninteresting that Albrecht (*Zoolog. Anzeiger*, 1880, Nos. 64 and 65), upon this same report, draws the opposite conclusion, and interprets the first vertebra of the Amphibia as his imaginary "pro-atlas" lying beyond the atlas, and the odontoid process of the Amphibia as the basioccipital separated from the cranium.

that the formation of the odontoid process out of the body of the atlas in the Amniota only begins among the reptiles.[31] In higher fishes it is very generally found that the anterior aspect of the first vertebra is not excavated, but slightly convex. Now, though it seems to me to be improbable that the conditions in Amphibia can be traced directly to these structures in fishes, yet here is a state of things that can be considered parallel with that of the Amphibia.

An explanation for the singular fact that in the higher fishes independent vertebra are co-ossified with the occiput is not difficult to find, and I believe the reason for this condition is to be found in the way and method in which the parasphenoid makes its appearance.

It has been fully and conclusively shown by Hertwig that teeth can be discovered upon all the bones of the buccal cavity, which arise from these osseous plates through sockets in their substance, and that the parasphenoid forms no exception to this rule, although teeth are found upon it far more seldom than on the other bones of the mouth. If we now know that the appearance of teeth in the Selachians is not confined to the cavity of the mouth, but that they also extend upon the mucous membrane of the fore-gut, as far as the gill slits, thus reaching far below the anterior extremity of the vertebral column, then the supposition will not be startling that the parasphenoid originally did not confine itself to the basis cranii, but extended far behind it upon the vertebral column.

In fact, we meet with the parasphenoid occupying this very position in those fishes in which bone first begins to appear, in the cartilaginous Ganoids, and in the Dipnoi. As already known, the parasphenoid of Stöhrs does not confine itself to the base of the true skull, but extends backwards to be applied to the inferior surface of the centra of about 7 or 8 vertebræ. According to Wiederscheim this is the arrangement in *Polypterus*, and Günther tells us that it also occurs in *Ceratodus*, only in these fishes the number of vertebræ covered by the parasphenoid is fewer. This also must have been the state of things in the direct ancestry of the existing bony Ganoids and Teleostei. Now, after the parasphenoid had ceased to be a tooth-bearing bone of the cavity of the mouth, a curtailment from behind took place, and at the same time a reduction in number and consolidation of the vertebræ resting upon this bone, which was already firmly connected with the cranium, set in, to replace the latter, a transformation the last traces of which can still be seen in bony Ganoids and Teleosteans.

The region of the labyrinth[32] is bounded posteriorly by the foramen

[31] Gegenbaur, *Grundzüge der vergl. Anatomie,* 2 Aufl., page 615.

[32] Labyrinth region, the term here used, applies more particularly to that space as seen in the Teleostei and bony Ganoids, which, by the way, it does not entirely include, as the labyrinth in these fishes generally extends beyond the confines given; moreover, all the bones enumerated by me as belonging to the occipital region may, under certain circumstances, serve for the inclosure of parts of this area. So I have retained the term simply to avoid a new name.

for the exit of the glossopharyngeus; anteriorly by the postorbital process and the posterior circumference of the orbit.

It forms the greater part of the lateral wall of the skull situated behind the orbits and includes the ossified petrosal and postfrontal.

The *petrosal* (Plate I, Figs. 2 and 3, *Pe*) is nearly circular in form, being connected behind and above by a small part of its periphery to the intercalare in a serrate suture.

It is separated from the surrounding bones by broad areas of cartilage, from the basioccipital posteriorly, the squamosal laterally and above, the postfrontal above and anteriorly, from the alisphenoid anteriorly, and from the petrosal of the opposite side by a mesial band of the same material.

Above the petrosal we find the long, flat, and longitudinally placed facet of articulation for the hyomandibular (Plate I, Figs. 2 and 3 *hm.*). This facet is entirely in cartilage, with the exception of the posterosuperior angle, which is slightly overlapped by a thin piece of the squamosal.

Anteriorly and above the petrosal lies the ossified postorbital process —the *postfrontal* (Plate I, Figs. 2 and 3, *Psf.*). This bone has the form of a triangular pyramid, whose apex is directed laterally and upward. The superior aspect of this bone, which is stamped with all the characters of a dermal bone, has already been thoroughly described; of the two remaining sides, one faces outward and the other assists in forming the hinder part of the upper margin of the orbit. The ossification of the postfrontal does not reach through the entire thickness of the lateral cartilaginous skull wall, but remains separated from the brain cavity at all points by cartilage. Now, at the dividing line between the bone and the cartilage there lies a canal that commences at the lower margin of the bone at the side of the skull and makes its exit at the anterior angle of the temporal fossa. So far as I could satisfy myself, it contains vessels intended for the soft parts contained in the temporal fossa. This canal has no greater morphological significance, and I only mention it for the sake of making my description complete. Two openings are formed near the anterior margin of the petrosal; the upper and larger one is for the facial nerve and jugular vein (Plate I, Figs. 2 and 3 *fa.*), the smaller and lower one for the carotid (Plate I, Fig. 3 *ca.*). While still in the brain case the facial nerve gives off a branch which, running forward, enters the orbit at the posterior margin of the fenestra—to be spoken of further on—thence traversing the lower lateral margin of this cavity, to be distributed to the mucous membrane of the mouth.

This branch of the facial, which universally occurs in the Teleosteans, has always been referred to as the homologue of the *ramus palatinus* of the Selachians. If one considers that the *ramus palatinus* of the Selachians always arises extracranial from the facial, and from this origin runs anteriorly, while the nerve bearing the same name in *Amia* and bony fishes has an intracranial origin, the question of their homology

becomes dubious. To render this homological comparison safe, we must have the positive proof, now missing, that this branch penetrates from the outer side of the skull to the inner in this series of fishes. The further distribution of the facial nerve after it quits the brain case is of no further interest in the present connection.

The orbital region is very definitely marked off. Its posterior boundary has already been alluded to; anteriorly the antiorbital process, with its ossification, the prefrontal, divides it from the nasal region. In *Amia* the orbits are tolerably flat and oval depressions, separated from one another in the median plane by an antero-projecting process of the cavum cranii (Figs. 9 and 10); there is not a trace present in *Amia* of a bony or membranous interorbital septum, as we find in so many of the Teleostei.

The roof of the orbit is formed only to a limited extent by a cartilaginous, laterally-projecting ledge of the primoidal cranium, which one may consider as the last remnant of a cartilaginous orbital roof (Figs. 2 and 3), the greater part of this roof being furnished by the frontal bone. An orbital base is indicated by a feebly developed, wing-like ledge projecting from the basis cranii, which is in contact with the parasphenoid beneath (Figs. 9 and 10).

The anterior third of the wall of the orbit is entirely cartilaginous,[33] while the posterior two-thirds are in part occupied by two ossifications. There is a large foramen found in the posterior part of the orbit, bounded above, behind, and in front by serrate edges of bone and below by cartilage, which opens into the brain case (Plate I, Figs. 2 and 3, *Op.*).

Posteriorly through this opening passes the optic and several other nerves out of the cranium, and through it the muscles of the eye reach the skull; anteriorly it is closed by a strong fibrous membrane. In many of the skulls of the Selachians one can see a fenestration of the lateral wall of the cranium, which is an extension of the foramen opticus, and it does not appear very improbable to me that the foramen I have just described in *Amia* is to be regarded as such a foramen opticus, much enlarged. At the boundary line between the labyrinth and orbital regions the cartilaginous base of the cranium is further pierced by a small foramen, which is covered by the parasphenoid, and which is only disclosed by removing that bone (Plate I, Fig. 3, *fh.*). This foramen in its position corresponds to the hypoplysis—to be described further on—and is to be compared in many bony fishes to that lengthened cleft at the base of the fossa for the muscles of the eye, which is closed by the parasphenoid.

The *alisphenoid*, constituting as it does the posterior ossification of the orbital region, is of a circular form, with a section cut from it below

[33] In a large specimen of *Amia* I saw the lateral, as well as the side toward the median plane—facing towards the cavum cranii—of this anterior orbital cartilage covered by a thin superficial layer of a brownish color, which at first sight looked like a very thin lamella of bone. A microscopical examination showed here that we had to deal with a calcification of the superficial layer of cartilage.

and anteriorly. This missing section is the foramen just described, and its outline depends upon it (Plate I, Figs. 2 and 3, *As.*).

Near its posterior margin the alisphenoid is perforated by a large circular foramen, intended for the second and third branch of the trigeminal. In large specimens of *Amia* the alisphenoid articulates above and posteriorly with the postfrontal; in younger individuals it is separated from the latter by a small zone of cartilage. Above the optic foramen, anteriorly, it is to a small extent suturally united with the orbitosphenoid.

Beyond the alisphenoid is found the *orbitosphenoid*, circular in outline and pierced behind and below for the optic foramen, of which nothing further will be remarked (Plate I, Figs. 2 and 3, *Os.*). It seems to me that at this point it would not be uninteresting to call attention to the circular form of so many of the ossifications of the primoidal cranium of *Amia*.

These forms are due to the fact that the centers of ossification start free in the cartilaginous matrix, and in their unhindered growth, which has been a proportionate increase of margin in all directions, they have but at a few places only been checked by contact with neighboring ossifications. In this respect, too, *Amia* has been preserved in a primitive condition, as compared with the Teleostei, in which the corresponding bones, owing to the fact of their contact at most points with their neighbors, exhibit a great irregularity of form.

The first branch of the trigeminus passes through the wall of the primoidal cranium at about the height of the anterior margin of the postfrontal, runs obliquely forwards and outwards, and quits the alisphenoid just above the large foramen for the second and third branch of the same nerve (Plate II, Fig. 6, *tr.*[34]).

During its course within the wall of the skull it gives off several minute branches, which ascend upward in the cartilage and pass to the mucus canals of the bones of the skull cover. In the orbits these branches are two in number, and lie parallel to each other; just beneath the "cover;" they pass forward to reach the nasal depression to which they are distributed, and in doing so pass between the cartilaginous cover of the primoidal cranium and the frontal.

During its entire course through the orbit it gives off minute ascending branches, which in part perforate the cartilaginous roof, described above as the remains of the vault of the orbit, which is composed of this material, while another branch passes to be distributed to the mucus canals of the frontal bone.

The second and third branches of the trigeminus nerve pass from the skull cavity through the foramen in the alisphenoid already referred to, and are distributed in precisely the same manner as they are in the Teleosteans (Plate II, Figs. 4 and 5, *Tr.*).

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[34] *Tr.* in the figure.—TRANS.

The oculomotorius and the trochlearis pass out through the large posterior foramen of the orbital region, at its posterior margin, the first-mentioned nerve above and the second beneath it.

Between these two nerves lies the group of straight eye muscles, of which the rectus externus is contained to some degree inside the cranium, and gives rise to the development of an eye-muscle canal.

Just anterior to the eye muscles, yet partly lying between them, we find the optic nerve, which in *Amia* is but feebly developed, owing to the small size of the eye. The ophthalmic artery, quite large in *Amia*, passes also into the bulbus with the optic. Between the last-named structures lies a strong fibrous cord, which arises at the posterior lower angle of the orbital cavity, to be inserted near the place of entrance of the optic on the bulbus. This cord corresponds in every respect to the *eye supports* in the Selachii. The two oblique muscles are inserted into the anterior angle of the orbit.

The nasal region of the primoidal skull of *Amia* is bounded behind by the antorbital processes, and has the shape of a triangular plate, bearing a superior median crest. With the exception of two small ossifications, the entire region is cartilaginous. On the inferior aspect of this region, situated mesially and in front of the antorbital processes, lie two oblong cartilaginous articulating facets for the anterior extremity of the palatine arch; the distal end of these touches the ossified part of this region, the *septomaxillare* (Plate I, Fig. 3, and Plate II, Fig. 5, *Smx.*). This is an osseous center that extends from the lower margin of the foramen for the nasal nerve to the lateral margin of the prenasal cartilage, and with which the maxillary is movably articulated at the latter place. The greater part of this small bone is covered above by the *intermaxillary*, and only becomes visible after this bone is removed. This bone has been declared identical by Bridge with the ossification at the base of the nasal capsule of the frog (the *septomaxillare*); and although I consider the homology thus assumed as at least improbable, still I did not introduce a new name.

It would appear to me more correct if Bridge had compared the two small ossifications known to us, which occur at the extremity of the cartilaginous rostrum of the Pike, with the septomaxillary of *Amia*, with which, indeed, they correspond in position as well as in their relation to the neighboring parts of the skeleton.

The cranial cavity is egg-shaped, with the apex directed forwards; that about the labyrinth region presents two niche-like depressions, for the concealment of the labyrinth, that are sharply defined as we proceed backwards towards the hinder extremity of the brain case. In *Amia*, as among the Selachii and Ganoids, this depression extends from the foramen magnum to the nasal fossæ. Not all of the ossifications of the primoidal cranium that are to be seen on the outer aspect are to be observed on the inner walls of the brain case or in the connecting spaces of the labyrinth; on the contrary, quite a number of them do not reach

through the entire thickness of the skull wall, and therefore remain separated from the cranial cavity by a layer of cartilage.

The exoccipital, the intercalare, and the post- and prefrontal are found to be in this condition.

It is hardly worth while mentioning that the squamosal also belongs to this category, applied as it is, in most fishes, to bound a portion of the outer arch; a like condition obtains in *Amia*, where, as has been fully discussed, it retains the character of a cover-bone throughout life.

Within the cavum cranii the anterior part of the occipital region is very sharply defined by an elevation directed anteriorly and towards the median line, composed partly of cartilage and partly of membrane, which runs along the lateral wall from above downwards, forming the posterior wall of the niche of the labyrinth. The base of this region is formed by the basioccipital, by the lateral walls, and for the greater part also by the cover-bone of the occipitalia lateralia; the adjoining portion of the spinal canal, which is covered by the occipital arch posteriorly, does not lie in the same plane with the base of the brain cavity, but is found higher up on the posterior wall of the skull, so there remains a fossa in this locality, which terminates blindly behind and below, over which the medulla oblongata and the anterior end of the spinal marrow pass. This depression is filled in with the now recognized interdural lymphatic fat tissue, [35] most extensively found in the Teleosteans, and becomes interesting to us for the reason that in the family of Characinides, Cyprinoides, the Shads and Gymnotides, it is this very depression that is partitioned off from the rest of the skull cavity by the crests of the occipitalia lateralia, which meet mesially, and is utilized for the formation of the "atrium sinus imparis," which is connected with the swim-bladder by means of the apparatus of Weber. The broad foramen for the vagus is situated at the anterior margin of the occipitale laterale. The anterior border of the labyrinth region within the brain case is formed by the anterior margin of the petrosal which does not join with the anterior bounding ledge of the labyrinth niche, but runs a little before it. The exceedingly complicated structure of the labyrinth niche, with the canals for the arches, is for the most part cartilaginous; its lateral wall is only formed by the petrosal below and anteriorly. The labyrinth is divided by a medial and projecting cartilaginous elevation, running anteroposteriorly and from above downwards into two fossæ, the smaller one being situated anteriorly and above, the larger one posteriorly and below; the former contains the greater part of the utriculus, the latter is intended for the sacculus with the recessus cochlearis. The recess for the sacculus forms, as I have already had occasion to state, quite a prominence on the lateral wall of the skull, which is to be regarded as the commencement

[35] Usually this fat tissue of fishes is taken for the arachnoid in these forms. I have reserved my full reason for a dissenting view for a later work.

of the *bulla acustica*, so extensively and in some cases excessively[36] developed in the Teleostei. I wish to state once more particularly that the canals intended for the arches, and bounded everywhere by cartilage, join with the labyrinth niche.

The anterior semicircular canal begins at the anterior upper portion of the utriculus inlet, courses laterally forwards and upwards, makes a turn in the vicinity of the postfrontal, running close beneath the cartilaginous skull cover, to be partly seen through it posteriorly and towards the median line, and finally terminates in the cavum cranii in an opening above the vestibule of the labyrinth (labyrinth niche). The outer semicircular canal takes its origin from the posterior portion of the utriculus, courses laterally and backwards, is barely seen just beneath the hyomandibular facet through the cartilaginous side wall of the skull, then proceeds backwards towards the median plane to find its exit, in common with the origin of the posterior canal, on the hinder boundary of the sacculus. During its course the outer canal approaches tolerably close to the intercalare. The posterior semicircular canal begins, as already stated, at the posterior margin of the sacculus, courses laterally backwards and upwards, comes almost in immediate contact with the exoccipital, then turns towards the median plane, forward, and makes its exit just above the vestibule of the labyrinth.

The description of the membranous labyrinth can be briefly presented. So far as I could convince myself from the specimens that were at my command, and really which were hardly suitable for a critical examination, it perfectly corresponds in its general structure with the labyrinth of the Teleostei, as we have learned from the admirable investigations made by Hasse.[37] It is described still more in detail by Retzius.[38]

The relation of the labyrinth to the cavum cranii in *Amia calva* shows a marked difference when compared with that of the Selachii. While in the Selachians the cavity of the labyrinth seems entirely isolated from the brain case, there exists in *Amia* and all other Ganoids and Teleosteans a more or less broad communication between these cavities. It would hardly be amiss if one would trace the causes of the varying size of the intercommunicating fenestra between the two cavities to the entirely disproportionate development and unfolding of the body of the labyrinth in the higher fishes, which has finally led to a stinted growth of the medial dividing wall of the same. The acusticus foramen has been in all probability the starting point for the fenestration of this wall. At least I think we are justified in assuming this from the position of this foramen of the labyrinth in *Amia* (when it is nothing more than the occurrence of absorption of the periphery of the foramen acus-

[36] In the *Scopelus* and *Gonostoma* I find a very extraordinary development of the bullæ acusticæ.

[37] C. Hasse, *Anatomische Studien*, Th. X. *Das Gehörorgan der Fische.* Leipzig, 1873.

[38] G. Retzius, *Das Gehörorgan der Wirbelthiere* [Vertebrates]. Th. 1. *Fische und Amphibien*, page 35. Stockholm, 1881.

ticus) as well as the fact that fenestrations in the skeleton in general are predisposed to proceed from the peripheries of the nerve foramina; as examples of which I would invite attention to the various foraminal perforations that occur at the points of exit of the cranial nerves in Selachians.

It is my wish now to make especial mention of certain important differences that exist between the labyrinth in *Amia* and that cavity in the Teleosteans. The more complete development of the labyrinth in osseous fishes has finally led to the belief that the still distinctly marked elevations that bound the labyrinth niches in *Amia*, where they occur in a rudimentary condition or are altogether absent, have resulted in a mergence of the cavity of the vestibule into the general cavity of the brain case, and that the labyrinth has really moved further backwards from its original position, appropriating parts that belonged to the occipital region, for its concealment. Besides, in the Teleostei the anterior arch has through a reduction in size of the broad cartilaginous strips, which in *Amia* separates it from the skull cavity, very frequently come to lie in the latter.

Finally, an important difference is seen in the fact that the almost entirely cartilaginous border of the labyrinth has in the Teleosteans been replaced for the greater part by a bony one. Underneath and behind the foramen for the facial, the petrosal throws off a horizontal lamella of bone, which in the middle line joins with the corresponding lamella of the opposite side, and forms the roof of a part of the cavum cranii that is closed posteriorly. It is the hindmost of the osseous part of the recess for the eye muscles, which is largely membranous in *Amia*, and of which an accurate description will be given further on.

While the limits of the separate regions of the skull are but feebly defined upon the skull-cover, quite a sharp definition takes place between the labyrinth and the orbital regions in the interior of the skull on its cover; this is through the means of a feebly-marked ledge, extending from one postorbital process to the other, and directed downwards towards the cavum cranii; here its lower edge meets the ascending epiphysis coming from below. This epiphyseal ledge of the skull-cover is constantly found in all Teleosteans, and represents in some individual cases the only remaining portion of the original cover of the primoidal skull.

The question which considers the channels through which the sound-waves of the surrounding medium reach the labyrinth in fishes has never, up to the present, been the subject of an exhaustive discussion. And yet the question deserves to be investigated, because quite a number of peculiar formations upon the skulls of fishes will become intelligible only after we have become acquainted with the nature of the sound-conducting channels. It does not demand any particular mention—inasmuch as an experiment is naturally out of the question—that the solution of this matter can only be brought about by critical

investigations of the topographical relations of the labyrinth region in the skulls of fishes, and the determination of the sound-conducting channels according to purely physical principles. The prevailing idea at present is that, in fishes generally, no special channels for the conduction of sounds have been differentiated; that, on the contrary, an entirely evenly-proportioned conduction takes place through the bones of the skull, and above all through its cover-bones. Specialized auxiliary apparatus of the ear, intended for the conduction of the sound-waves to the labyrinth, with the least possible loss, are said to appear first in the class Amphibia; this is positively erroneous. A superficial review of the majority of fishes demonstrates the improbability of this assumption. In the vast majority of fishes the bones of the cranium at no place enter into contact with the surrounding medium, but are separated from it by extraordinarily poor sound-conductors, by a thick swardy skin, and frequently even by powerful layers of muscles, so that the conduction of the sound-waves directly through the bones of the head can be counted on in a comparatively very small number of fishes only, as in those whose heads are covered by naked bone-shields. The possibility that it takes place through a general conduction on the part of the bones must be absolutely set aside for the vast majority of fishes, and we will have to look about us for other channels of conduction.

Such a channel has been found for us by Hasse[39] in the Clupeidæ. He found that that portion of the auditory capsule, which bounds the sacculus laterally, forms the inner wall of the gill cavity, and so enables the sound-waves to infringe upon the sacculus through this space. These observations are correct, only that Hasse has erred in that he regards the intimate relations of the labyrinth to the gill cavity as confined to the Clupeidæ, whereas it occurs in the majority of osseous fishes. In a large number of these latter, representatives of the most widely separated families, I found almost without exception that the anterior superior apical recess of the gill cavity lies in close juxtaposition with the labyrinth region of the skull, consequently at this point the water present in the gill cavity is only separated from the thin, lateral osseous or cartilaginous wall of the labyrinth by a thin mucous membrane. In numerous cases, in which the sacculus with its otoliths is fully developed and forms a lateral jutting bulla on the skull, this bulla almost without exception projects into the gill cavity, and in many instances can be felt from the gill cavity by the finger with great ease. Yet I would have it distinctly understood that in most cases it is not the sacculus alone that has this relation to the gill cavity, but that the utriculus also enjoys a similar relation, and so it is not admissible here to

[39] C. Hasse, *Anatomische Studien; Suppl. Die vergleichende Morphologie des häutigen Gehörgangs der Wirbelthiere*, 1873, page 53. [C. Hasse, Anatomical Studies; Suppl. The comparative morphology of the membranous auditory passage of the vertebrated animals, 1873, page 53.]

assume, as Hasse did, that we are dealing with a sound-conducting channel or medium specially intended for the sacculus. At present I cannot yet enter upon the details of the relations of the labyrinth to the gill cavity in the Teleostei, to which I must refer to special descriptions to be published later, upon the crania of separate families of osseous fishes.

Now that the grounds for the assumption have been demonstrated, that in bony fishes the sound-waves for the most part reach the labyrinth from the gill cavity, the remaining question presents itself as to how the sound-waves get into the gill cavity. There can be no doubt that the gill cleft plays an important part here; still I believe I am able to point out yet another channel which, according to physical principles, must be even better suited for the purpose. I mean the conduit which is presented in the bones of the opercular apparatus, especially by the operculum and sub-operculum. If one reflects that these bones are thin elastic plates in most Teleosteans, which through their broad surface are in contact with the water contained in the gill cavity, and covered as they are by a thin skin only, and at no time being covered by large masses of soft parts; then one must admit that an apparatus, thoroughly suited to the purpose, here presents itself for the conduction of the sound-waves from the outer medium to the body of water in the gill cavity. Should further investigations confirm this supposition, it would establish the statement formerly made by Geoffroy St. Hilaire who, as we are aware, declared that the opercular bones were ossicula auditus; to be sure in an entirely different sense from what this author meant. Although somewhat foreign to the subject of my paper, a comparison of the sound-conducting media of the bony fishes with those parts in other vertebrated animals, especially the Selachii, is of great interest, because such comparisons very well illustrate the position that the Teleosteans hold with respect to other vertebrates.

The common opinion is, that differentiated sound-conducting apparatuses first made their appearances in the Amphibia, more particularly among the Anura. It has already been sufficiently dwelt upon that this view is an erroneous one, and that in the majority of bony fishes no *general* conduction of the sound-waves to the labyrinth takes place; that, on the contrary, channels have been differentiated of a constant character. But osseous fishes are not the forms—in the vertebrate series—in which such auxiliary apparatuses to the organ of hearing first appear; contrivances for such purposes can already be demonstrated to exist in the Selachians, from which the apparatuses in the bony fishes were derived. The credit belongs to Johannes Müller[40] for being the first to truly recognize and appreciate these conditions in the Selachians;

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[40] *Vergleichende Anatomie der Myxinoiden. Theil III. Das Gefässystem der Myxinoiden. Abhandl. d. Berlin. Akademie d. Wissenschaften von Jahre* 1843. [Comparative Anatomy of Myxinoids. Part III. The vascular system of the Myxinoids. Treat. of the Berlin Academy of Sciences, 1843.]

unfortunately his observations appear to have entirely passed into oblivion, at least I have not come across a single allusion to them in the writings of the more recent authors. The sound-conducting apparatus in the Selachians is the hyomandibular cleft. This starts, as we know, with a wide opening in the buccal cavity in a position nearer the median plane than the opening of the first gill cleft, and close to it, and then courses upwards between the hyomandibular and the palatoquadratum, making its exit either in an opening, the aforesaid hyomandibular cleft, behind and above the eye, or ending blindly beneath the skin. During its course this canal lies close to the labyrinth region, and in individual cases it even presents special blind diverticles, which adhere closely to it. This is the point in Selachians where the labyrinth is nearest the surrounding medium, and through this channel the sound-waves must reach it the least diminished in intensity. That they may be conducted, too, from the surface of the head, is by no means to be set aside—such general transmission, to a limited extent even taking place in man through parts of the skeleton of the head—yet the idea of such a conduction in the Selachians, if the parts concerned are investigated according to physical principles, must be utterly abandoned, when we come to compare this with the part played as a conductor by the hyomandibular cleft [*speitzloch canal*]. The sound-waves to only a limited degree can enter the hyomandibular cleft from the cavity of the mouth, and will at least in cases where there is a wide, open, external cleft existing, find their entrance through it.

The fact that the hyomandibular cleft of the Selachians being homologous with the tympanic cavity and the canals in the higher vertebrates, and exercising a similar function, is certainly very remarkable. This demonstration effects the removal of one difficulty, and that is the belief that the tympanic cavity and the canals first originated among the air-breathing vertebrates. In fact it was scarcely at all understood how for this purpose, a gill cleft, whose very existence depends upon its being constantly in water, could continue to exercise its true function, and still to some extent be subservient to the organ of hearing. This difficulty is completely set aside by the discovery that the sound-conducting function of the anterior gill cleft is not a new acquisition in land vertebrates, but that it also existed in their ancestors living in the water; and with these the reason [*ursächliche moment*] for this is also furnished, why this gill cleft could still survive, retaining its integrity to the very last and in the most advanced vertebrates in the scale of development, while the other gill clefts, originally provided with respiratorial functions, have disappeared without leaving a trace, having commenced in the Dipnoi and Amphibia with the development of a new respiratory organ.

After what we have just demonstrated, the fact that the Urodela and several of the Anura possess no tympanic cavities or Eustachian tubes, is to be differently construed from what it has been heretofore. Here,

without doubt, a retrogressive process is presented us, as in the snakes; and the alternative proposition, that in these forms a middle ear has not yet developed, is untenable. In fact it would be incomprehensible, if the closed foremost gill cleft of the higher Amphibia were to reopen itself and re-enlist its functions in connection with the auditory apparatus. Equally unintelligible would be the occurrence of the columella in Urodela—a part of the skeleton whose origin is closely associated with the development of the middle ear, and if it existed by itself its need could not be understood, inasmuch as no function for it could be discovered.

The question now remains whether the apparatuses we have just described for the bony fishes and the Selachians originated entirely independently of each other, as appeared at the first glance, or whether there are not organs somewhere in existence which constitute the connecting links between them, and allow a genetic connection of these apparently entirely different formations to be entertained.

A direct comparison of the apparatuses in the Selachians with the Teleosteans leads to an unsafe result, inasmuch as the topographical appearances on the skulls of these forms are entirely different, and as a natural consequence the various relations of the parts cannot be compared with each other in detail; therefore it only remains for us to look about us for the intermediate forms and through them attempt the solution of the question. Such an absolutely intermediate form—of course only for the purpose mentioned—is *Polypterus*. While the cranium of this Sauroid, and particularly its maxillary apparatus and gill apparatus, very closely approach the Teleostean type, the *Polypterus* during life possesses a well-developed hyomandibular cleft, and in this respect reminds us of the Selachians. The inner, capacious opening of this cleft lies in the gill cavity; it is bounded mesially by the epibranchiæ of the first gill arch, posteriorly by the anterior margin of the hyomandibular, and laterally by the bones of the palatal arch. This wide hyomandibular cleft takes an upward direction, lying close to the labyrinth region of the skull, to make its exit at the upper and lateral margin of the cranium in a slit-like opening, that is covered by two small dermal bones, which act like valves. In *Polypterus* the conduction of the sound-waves to the labyrinth can scarcely take place through the outer opening, closed as it is by the small dermal bones just referred to, so we must believe that the sound-waves enter at the inner and least difficult opening, as this does not open into the buccal cavity—as in the Selachians—but into the gill cavity, which is in complete communication with the outer medium.

A comparison of the hyomandibular cleft in *Polypterus* with the blind apical recess lying close to the labyrinth region in bony fishes places it beyond all doubt that they are homologous structures, and that this recess of the gill cavity, which was alluded to when speaking of the Teleosteans, is nothing more than the hyomandibular cleft which has

become widened and closed up at its dorsal aspect. An anatomical reason for this closure, I believe, must be looked for in the development of the hyomandibular in bony fishes. While in the Selachians this part of the skeleton is a slender cartilaginous rod; in osseous fishes it becomes more extensive, in conformity with the greater development and differentiation of the muscular system of the maxillary apparatus, so as to form a broad plate. Correlated with this, we also find the articular facet for this bone in Teleosteans, extending so far as the postorbital process, which extension anteriorily closes the hyomandibular cleft. The relations of the main trunk of the facial nerve—the *truncus hyoides mandibularis*—affords the strongest proof that this extension was in anterior direction, or towards the anterior extremity of the body. In Selachians this nerve passes close to the hyomandibular, coursing downwards in front of its anterior margin, while in the Teleosteans, in the majority of forms, it perforates the hyomandibular bone in order to reach the outer side. It requires no special demonstration to show that such an apparent perforation of the bone could only have been accomplished by its growth forwards, inclosing the nerve as it did so. At the same time the hyomandibular cleft had to be necessarily closed up and transformed into a blind recess in the gill cavity and with the same topographical relations with the labyrinth as we have described for it.

At the base of the orbital region, in the interior of the skull, there is a depression which is well defined both anteriorly and posteriorly, that reminds us to some degree of the sella turcica of the higher vertebrates (Plate II, Fig. 4). Posteriorly, this depression is continued beneath the processes of the petrosal bone, already referred to, where it terminates; anteriorly it is bounded by a bar of cartilage, which contains an osseous center at each lateral angle. At the base of this pit there is a breach in the primoidal cranium, already mentioned, which is closed in below by the parasphenoid. In the direction of the cavum cranii, speaking in a more limited sense, this pit is entirely closed by a strong membrane, which glistens like a tendon. This latter spans the space between the anterior sharp margin of the united and horizontal wings of the *ossa petrosa* to the foremost cartilaginous bar. This membrane extends far up the lateral walls of the skull, and becomes attached about half way up to a sharp bony crest that is developed downwards and mesially from the ali- and orbito sphenoid (Fig. 7, *Kl.*[41]). The posterior part of this upper extension of fascia ensheaths the trigeminal and facial nerves near their points of exit from the skull; the anterior part of this fascia is the membrane that closes the optic foramen.

This fascia divides off another space, situated below and somewhat laterally from the true cavity of the skull, which of course is intended for the brain. The greater part of this space is filled in with the well-known lymphoid fat tissue, found so extensively throughout the fishes, that is also contained in the remaining part of the cavum cranii in

[41] Dr. Sagemehl has failed to place these letters on his figure.—Trans.

Amia; there are also nerves and muscles to be found in it. The facial, with its ramus palatinus, and the trigeminus course through the postero-lateral divisions of this space, as already stated, between the membrane and the bony lateral wall of the skull for some distance before they arrive at their foramina of exit. In the anterior part of this space the membrane is perforated by the opticus.

In the lower part of this cavity, which is separated as we have described from the brain case, are to be found the points of origin of the external rectus muscle. These arise near each other not far from the median line, close behind the cartilaginous transverse bar, already referred to above, that forms the anterior boundary of the sella turcica; anteriorly these muscles diverge from each other, each to enter an orbit through the optic foramen on either side. So we find in *Amia*, as in so many of the bony fishes, a subcranial canal, which to be sure is but feebly defined, lacking as it does a superior osseous partition to divide it from the cranial cavity. The nervus abducens perforates the fascia from above, and immediately passes into the substance of the external rectus muscle, so that it is not visible in the orbit proper. In addition to this, the principal branches of the carotid artery are to be found in this subcranial canal. Upon the membrane above this canal lie the *hypophysis cerebri* and the *lobus vasculosus* in a feebly developed funnel-shaped depression.

We will now turn our attention again to the two ossifications, found in the lateral angles of the anterior cartilaginous bar. These cannot be observed from the outside, and it is only in the dissected skull and after the fascia has been removed, that they are exposed to view. Bridge has called these parial ossifications the basisphenoidea and declares that they are homologous with the well-known Y-shaped basisphenoid of many of the osseous fishes.

This statement I fully indorse. If we bear in mind that besides the *recti externi*, the other muscles of the eye also make their appearance in the cavum cranii, then the cartilaginous partition lying between these two groups of muscles must necessarily be implicated, and the two centers of ossification already spoken of must through extension eventually meet and merge into each other, forming a non-parial bone, situated between the muscles of the right and left bulbus. It is then that we have the conditions presented to us seen in so many of the bony fishes.

If this explanation be not accepted, then we must see in *Amia* certain ossifications that occur in no other fish, and must deny *Amia* a bone of very frequent occurrence.

The next thing before us is to compare the subcranial canal, which lodges the muscles of the eye in *Amia* with that canal as found in osseous fishes, and endeavor to ascertain whether it cannot be traced to a known and similar structure in forms occupying a lower position in the scale. I will first briefly compare it with the canal as found in the Teleostei.

The principal difference between the subcranial canal for the eye muscles in *Amia* and that in bony fishes, is seen in the fact that in the latter it is separated from the brain case proper by an osseous partition, while in *Amia* this is composed only of membrane. In articles I have yet to publish, it is my intention to show how this osseous partition is developed in bony fishes from the neighboring bones, more particularly the petrosal, by their throwing out horizontal processes that meet to ossify in the median line of the skull. Commonly, too, this subcranial canal extends farther back in osseous fishes than it does in *Amia*, even to extend into the basioccipital. This results from the muscles of the eye being longer in these forms, and consequently a canal of proper length developes to accommodate them.

Concerning the phylogenetic origin of the subcranial canal, Gegenbaur conjectures that the *canalis transversus* of the Selachians is the subcranial canal of the Teleostei, in which the muscles of the eye find lodgment.[42] In the Selachians this canal passes from one orbit to the other, obliquely through the cartilaginous basis cranii, causing the two periorbital lymph sinuses to merge into one; in some cases it is separated from the brain case by membrane only. Immediately in front of this *canalis transversus* are found the openings for the carotids, which in some forms are separated from the former also only by membrane. In the orbits the recti muscles are inserted nearest to the anterior entrance of the subcranial canal. Quite close to this we also find—at least in several Selachians (*Hexanchus*)—the foramen of exit for the nervus abducens.

A great deal in the structure of the parts in question, so far as examined in *Amia*, goes to support this view. Above all, the fact must be noted that in *Amia* the canal separated from the cavum cranii is not entirely devoted to the eye muscles, as in the Teleostei, but is largely filled in by the lymphoid tissue.

Now, since we have not the least ground for assuming that *Amia* is descended from forms in which the muscles of the eye were far better developed, and filled the space alluded to entirely, there is but one hypothesis possible, that *Amia* has in this region a preformed lymphatic fossa situated at the basis cranii, into which the points of origin of the *recti externi* only moved secondarily. But this preformed lymphatic space—if we are to judge from homologous structure in inferiorly organized fishes—can only correspond to the *canalis transversus* of the Selachii, which, in *Amia*, is remarkably widened and spread out, and which has finally included the carotid canals and the surrounding nerves found near the exits of these vessels. At the same time its cartilaginous

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[42] C. Gegenbaur, *Untersuchungen zur vergl. Anatomie d. Wirbelthiere. Heft III. Das Koffskelet d. Selachier*, 1872, pag. 78. [C. Gegenbaur, Observations upon the Comparative Anatomy of Vertebrates. Part III. The skeleton of the head in Selachii, 1872, p. 78.]

roof was replaced by a membranous one. So long as such organizations exist and no intermediate forms are known to us between the primitive structures seen in the Selachians and the relatively and already widely differentiated organization of *Amia*, this view of Gegenbaur's must remain an hypothesis; an hypothesis, to be sure, that has much to support it. By accepting it, the survival of the transverse canal of the Selachii is accounted for in higher vertebrates, if nothing else, and one is not compelled to advance the dubious proposition that there exists in *Amia*, and in Teleosteans descended from *Amia*, a canal beneath the cavum cranii, unique in the sense of being without antecedents, and whose importance and homology would be quite enigmatical. The olfactory region presents for examination two spacious canals in the interior of the skull, running side by side, parallel and in an antero-posterior direction, which are separated from each other by a broad cartilaginous septum, and which end in the foramina olfactoria at the base of the nasal fossæ. In the canals, which are to be considered as the direct continuation of the cavum cranii, are to be found the very thick and firm olfactory nerves. They are composed of a strong neurilemma which surrounds a fasciculus of nerve fibers, some seven or eight in number, but loosely connected together, and among which, to all appearances, no anastomoses take place.

In fishes, as we are aware, two types can be distinguished, depending upon the relations existing between the nerve center of the olfactory organs and their terminal filaments. In one case the bulbi olfactorii of the olfactory mucous membrane lie close by, and are connected with the fore brain by a long tractus; a single olfactory nerve does not exist in this case, but rather, on the other hand, quite a number of short nerve fibers pass from the bulbus to the olfactory mucous membrane. In the other case the bulbi olfactorii are connected with the hemispheres of the cerebrum and arise as long and true olfactory nerves. At first sight it would appear as though the difference was not an essential one, and as though the bulbus olfactorius was no integral part of the brain, but simply a collection of ganglionic cells occurring in the course of the fibers of the olfactory, and could occupy divers positions. That it is, however, is clear when we see the typical, very characteristic, difference between the stout olfactory nerve, provided with a firm neurilemma, and distributed to the periphery from the bulbus, and the thin tractus, enveloped only in the delicate pia mater holding a central position with respect to the bulbus. This same fact was particularly dwelt upon by Stannius,[43] that these two specified conditions as regards the position of the bulbi olfactorii are always independently present, that there is either a bulbus adjacent to the brain or one annexed to the olfactory membrane; cases in which a centrally located bulbus occurs in connec-

[43] Stannius, *Das peripherische nervensystem d. Fische*, 1849, page 2. [Stannius, The Peripheral Nervous system of Fishes, 1849, p. 2.]

tion with ganglionic enlargements at the distal extremity of the olfactroy nervelets do not exist.

Besides, there are—though very rare—intermediate forms known between the two types we have indicated among fishes; cases, for instance, where the bulbus is placed half-way between the brain and the olfactory membrane, and where it is connected with the former by a thin, soft tractus; with the latter by a strong, firm nerve at least four times as thick. The only other case of this kind known up to the present time has been noticed by Stannius in the *Gadus raniceps fuscus;* and I find quite a similar condition in the Characinidæ, as in *Hydrocyon* and *Alestes.*

A mere superficial examination of these two types does not furnish us with sufficient data to judge from, and decide which is the primary form and which is the derived one. As in so many other cases, the question can only be decided by the systematic—based upon other conditions of organization—position of the forms that belong to one or the other type. We now find that the first type occurs in all Selachians, in Holocephals, and certain of the Teleostean groups, long known to us as the primitive forms, as in the Siluroids, the Cyprinoids, the Gadidæ, and, as I have found, also in the Mormyridæ.

The second type is extensively found in the Ganoids and in the great majority of the Teleosteans. With all this before us, no doubt can remain that the first type is the primitive one, and that from it the other type has developed by a gradual shortening of the tractus and a lengthening out of the nerve.

It appears that in the Teleosteans the development of the olfactory nerve is always brought about in the same way and with a uniform result. The enlargement of the orbits leads to a fenestration of the lateral orbital wall at its anterior angle near where the bulbus olfactorius was originally located, as one can see very well in the Characinides; this development extending further gives rise to an olfactory nerve, which must of necessity pass through the orbits. These conditions appear to be quite constant among the Teleosteans. Among a great number of very diverse forms I have always found either an olfactory nerve in the orbit or a long tractus extending directly from the brain case to the nasal pit.

In *Hydrocyon*, already referred to, the bulbus lies in a special elevation in the orbito-sphenoid; from it a nerve is given off that passes to the olfactory membrane, being free in the orbital cavity; and a long tractus lying within the cavum cranii to the fore-brain, so that in this case there is no exception to the general rule.

. A remarkable exception to this rule is found in all the Ganoids. In these fishes a true olfactory nerve passes within the direct continuation of the brain case, and consequently proves to be a condition that must have arisen under circumstances to us nearly unknown and entirely

different from those of the bony fishes, and, therefore, bears no genetic relation to the latter.

Lepidosteus alone seems to form an exception to this unvarying rule among the other Ganoids. The olfactory nerve in *Lepidosteus* at first passes into a tunnel-shaped osseous tube, formed by the alisphenoid. At the posterior part of the orbit it quits this tube and passes close beside the semicartilaginous, semimembranous interorbital septum; consequently at this point its course is free in the orbit. At the anterior part of the orbit both nerves enter a very long cartilaginous double tube, which corresponds to that portion of the long rostrum of this fish belonging to the primoidal cranium. At first glance we seem to have presented us here a method of development corresponding in every sense with that seen in the majority of bony fishes, yet this is by no means the case. As already stated, the fenestration of the lateral wall of the skull in the nasal region of bony fishes begins at the anterior part of the orbit, at the place where the bulbus olfactorius occupies a near position to the olfactory mucous membrane, and which leads to a marked separation of the same from the membrana olfactoria, and to the lengthening of the olfactory nerve. In *Lepidosteus* this long double tube, in which the nerves are contained, is to be considered as the original direct continuation of the skull cavity; therefore the development of an interorbital septum in this fish cannot have come about in the same way that it did in the bony fishes, nor can the necessity for the origin of the olfactory nerve be looked for in this fenestration. This nerve must have originally in *Lepidosteus*, as well as in the other Ganoids, been contained for its entire length in a continuation of the brain case, which was separated by a median dividing partition into two canals; subsequently the lateral partition in the posterior interorbital part of this septum disappeared, and in this way the olfactory nerve came to lie in the orbit.

In the course of this essay it would have been quite an easy matter for me, in more instances than one, to have pointed out the facts going to show that quite a number of the various structures in the bony fishes can be traced with tolerable certainty to *Amia*, and from this the opinion naturally arises that the same will apply to all the organs, and that *Amia* is in reality a direct ancestor of the family of Teleosteans.

For this reason I have the more eagerly seized upon the opportunity to point out the conditions referred to above with respect to the development of the olfactory nerve, in which particular *Amia* has decidedly reached a higher degree of organization than certain osseous fishes lower down in the scale.

In this place I will not omit the consideration of the morphological conditions of the peripheral olfactory organs of the Ganoids and Teleostei somewhat more critically, and compare them with corresponding conditions in the Selachians.

In the lowly organized Sharks, as, for example, the Notidanides and Acanthias, there exists upon the inferior aspect of the snout, on either side, a single nasal aperture, which is incompletely divided by two processes, the nasal flaps, which spring from its margin, and give rise in this way to a medial and a lateral entrance.

In the more highly organized Selachians, in the Scyllians, among the sharks, and in many rays, a more or less deep groove is found to extend from the medial entrance to the upper margin of the buccal aperture. This is the well-known naso-labial groove, which also appears in the ontogeny of the higher vertebrates, and for the closure of which the median nasal aperture is furnished with a valve, found on the margin of the upper lip and opening in the direction of the nasal cavity. This latter corresponds to the inner nasal opening of the Dipnoi, Amphibia, and Amniota. These structures have long since been described by Gegenbaur, and the question only concerns us with respect to the Teleosteans and Ganoids.[44] According to previous notions—still accepted by Gegenbaur—the two openings of the nasal pit in bony fishes and Ganoids correspond to the imperfectly separated nasal valves of the lowly organized Selachii. Balfour[45] has placed a different interpretation upon this. According to his views in the matter, the posterior nasal aperture of the higher fishes are homologous with the inner nasal apertures of air-breathing vertebrates, which by a gradual turning of the axis of the nasal capsule have shifted their position from the upper lip to the superior aspect of the head.

My observations upon fishes compels me to oppose this view, and adhere to the old opinion. There are two arguments that I must cite which conflict with Balfour's notion: one of comparative anatomy and one of the history of development. In a number of Teleostei, among others, all native Cyprinoids examined by me, I found in the immediate neighborhood of the nasal apertures and in the dermal bridge separating the anterior and posterior aperture, a small cartilage, that remained undescribed up to the present time, and that is strictly homologous with the nasal alar cartilage of the Selachians. This cartilage usually has the form of a figure 8, the two loops surrounding the nasal openings and the middle piece lying in the dermal bridge between the apertures. It is very intimately connected with the skin, so that it becomes a difficult matter to make a dissection simply trusting to the scalpel and forceps, but by the aid of a microscope, and carrying the incisions through the nasal region, one can very easily satisfy himself of its presence. It possesses the characteristics of hyaline cartilage and differs

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[44] C. Gegenbaur, *Grundzüge der vgl. Anatomie, II Aufl.*, 1870, pag. 754, *und das Kopfskelet der Selachier*, 1872, pag. 97 *u* 216. [C. Gegenbaur, Elements of Comp. Anatomy, II Edit., 1870, page 754, and the skeleton of the Selachian head, 1872, pages 97 and 216.]

[45] F. M. Balfour, Manual of Comparative Embryology, 1881, Vol. II, page 477.

from the cartilage of the primoidal cranium, with which it is in no way connected, by its much denser cartilage cells.

In many cases among the Selachii, too, does the nasal alar cartilage encircle these apertures as a ring, sending out processes into the nasal valves. If one pictures to himself that the nasal valves of the Selachians have become merged with each other during their growth or development, and the cartilaginous processes contained within them become blended, there will result as a consequence a condition that can in no way be distinguished from the state of things as seen in the Teleostei. That this view is the correct one is shown by the history of the development of the nasal organ in the bony fishes.

In newly-born fishes there exists on either side a simple undivided nasal aperture, as I have observed in the *Lota vulgaris*, in the Pike, in the Trout, and in the *Chondostroma nasus*. It is not until these forms have passed the embryonic stage does there occur, sooner or later, a division of this aperture into anterior and posterior nares. Both the median and lateral periphery develops a small patch of skin, directed towards the center of the aperture. Very soon these processes that correspond to the nasal valves in the Selachii become contiguous, the lateral process being behind the median in all of the specimens examined by me. At this stage the nares in osseous fishes have reached the precise condition that remains permanently in Notidanides and *Acanthias*.

In a short time these two nasal valves of bony fishes blend together and the narial opening receives its definite shape, at least for those forms in which the two apertures are situated close to each other. Inasmuch as the primary conditions are not exactly so arranged in *Lota vulgaris*, whose anterior and posterior nares, after it has arrived at maturity, are far removed from each other, there must occur in this species a widening of the nasal bridge and a separation of the nasal apertures at a later period (unfortunately I lack the material to illustrate these stages). At any rate fishes with the anterior and posterior nares close together are to be considered as primitive forms, and from such, forms can be traced in which these apertures are far apart. Such forms, then, are to be considered as the highest in the scale of development in a certain direction, in which the narial apertures are far apart and are situated on the upper lip.

Such formations among bony fishes occur in *Ophisurus* and kindred forms,[46] in the family of Murænoids, and, in fact, they have at the first glance a certain resemblance to corresponding structures in Dipnoi and perennibranchiates, and it does not appear improbable to me that this peculiarity of the *Ophisurus* led Balfour to assert a homology of the

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[46]Lütken, *Nogle Bemaerkninger om Naeseboreunes Stilling hos de i Gruppe med Ophisurus staaende Slaegter af Aale familien. Videnskabl. Meddelelser fra d. naturhistoriske Forening i Kjöbenhavn*, 1851.

posterior nasal aperture in osseous fishes with the posterior nares of the air-breathing vertebrates.

A comparison extended to a greater number of forms and the history of development clears up the actual state of affairs in this case also, and demonstrates that it is but an interesting case of "converging development" ["*konvergenten entwicklung*"]. The position held by those Teleosteans which permanently possess but one nasal aperture on either side, as for example *Belone*, the Pomacentrides, many Chromides, &c., is only to be determined with absolute certainty when we have a knowledge of the history of their development. If one, however, considers that the nearest kin to these fishes (Cyprinodonta, Labroidæ) exhibit the ordinary conditions, it will hardly be out of place to simply assume that the dividing dermal bridge between the nasal apertures in the form referred to has been secondarily reduced.

As in so many other structures, so in those of the nasal apertures, the lowly organized Selachii prove to be the starting point from which two diverging series can be traced; upon one side the higher fishes, on the other the air-breathing vertebrates.

As I have already mentioned, the anterior and posterior nares in *Amia* are far apart, and, consequently, *Amia* represents a form that must, as compared with the ordinary bony fishes, be accepted as possessing a higher state of development. The *nasal bone* is imbedded in the broad dermal bridge between the two nostrils. Under these circumstances it is not at all strange that, in spite of the careful search I made for it in this fish, I could not find the trace of a nasal alar cartilage in the vicinity of the nostrils. The nasal has taken upon itself the original function of the same, that is, to support the entrance to the nares, and thus rendered a nasal alar cartilage superfluous.

To conclude the present article it only remains for me to draw a comparison between the cranium of *Amia* and that of the Selachii, with which it may best be compared, and to particularize their resemblances and their differences. Taken as a whole the latter are fewer in number than one would at first suppose. The fundamental difference between the skull of *Amia* and that of the Selachians rests upon the appearance of the large connecting ossifications in the former. These ossifications either simply overlie the primoidal cranium, or they are connected very intimately with it, and without changing their form, replace structures in it that were originally cartilaginous.

The first appearance of the larger uniting masses of osseous tissue among fishes denotes one of the greatest and most far-reaching steps in the progress of the process of development of vertebrate animals. It indicates the first appearance of a tissue that, as a protective and supporting material, proves far more suitable than cartilage. A glance at a series of skulls of Selachians and Teleosteans will be sufficient at once to demonstrate the great significance of this "occurrence."

The entire organization has become changed. A pleasing, graceful structure has taken the place of the clumsy Selachian skull. The delicate and rounded contours of the latter are replaced by angular, and quite often by oddly-shaped skulls, on which the grooves for muscular attachment and tendon insertion are distinctly marked. The new material substituted for the building up of these structures far surpasses the old, not only in its capacity for resistance, but also is greatly superior to it in its fitness for plastic modelling. In this particular, one finds very marked gradations even among the higher fishes. In their rounded contours, and in the imperfectly developed muscular grooves and crests, the bony Ganoids and a number of the Physostoma remind one very much of the Selachians; and it is only in those groups of fishes exhibiting the highest development, more particularly Acanthopterygii, that the types of extreme differentiation come into bold relief.

Leaving out of consideration the fact that it partly consists of different material, the primoidal cranium shows but few points of difference from that of the Selachii. In the first place, by the co-ossification of several vertebræ, the occipital region in *Amia* has attained a distinct morphological value, differentiating it from the corresponding regions in the Selachians, without having its form essentially changed by the process. Compared with the Selachians it has increased considerably, but in length only, which is sufficiently accounted for by the circumstance just mentioned.

The posterior part of the skull cover, in the vicinity of the occipital region, presents a structure that already esssentially exists in the Selachii. The median, cartilaginous process, pointing posterially, is present in the Notidanides, being developed there as a cartilaginous crest. Nor is it difficult to recognize in the medial projections occupied by the exoccipitals in *Amia*, the cartilaginous elevations developed upon the projecting posterior arches of the Selachians. The posterior lateral angles of the skull, formed in *Amia* by the intercalare, are also very well developed already in some of the sharks, as, for example, in *Scyllium*. Between the crest of the posterior arch and the last-mentioned lateral projection of the skull in the Scyllia there can already be recognized a depression in the cranical vault, extending into the region of the postorbital process, which in *Amia* is bridged over by the overlying dermal bones, closing in the temporal fossæ. In the region of the labyrinth of the Selachians we find this cavity closed up on the side towards the cavum cranii; in *Amia* it is widely opened, probably a fenestration proceeding from the periphery of the acusticus foramen.

Upon the outer aspect of the labyrinth region, the changes occasioned by the presence of the articular facet for the hyomandibular, are the most striking. I have already availed myself of the opportunity to point out, in the higher fishes, the extension of the hyomandibular forwards as far as the postorbital process.

At this point I would remark, that in the matter of position of the hyomandibular articulation, it is the Notidanides among all the Selachians, that still most resembles *Amia* and the Teleostei.

The parietal grooves which occur in the skull cover of many Selachians, and which include the broad, blind terminal parts of the aquæducti vestibuli, are missing in all the Ganoids and Teleosteans. This has evidently something to do with the very imperfect development of the aquæducti in the higher fishes as compared with that structure in the Selachii.

At the base of the primoidal skull we invariably find in higher fishes a fenestration in the region of the hypophysis cerebri that is lacking in the Selachii.

Postorbital and antorbital processes occur in most of the Selachii as well as in *Amia* and most all the Teleostei.

The optic foramen of the Selachii—already exhibiting evidences of increasing size—is represented in the orbital region of *Amia* by an extensive vacuity.

The cartilaginous peduncle which supports the eye in many Selachians, is in *Amia* reduced to a fibrous cord. Only the merest traces exist in the orbits of *Amia* of that basal projecting ledge of the primoidal cranium and the vault as they occur in the Selachii.

The very characteristic vacuity which occurs in the prefrontal coverbone of the primoidal skull in the Selachii is wanting in *Amia*, but appears to be present in certain families of osseous fishes, in Cyprinoids and Characinids.

Not a few differences in the structure of the nasal region between the Selachii and the higher fishes, including *Amia*, can be made out. While the nasal apertures in the Selachians are situated upon the lower aspect of the snout, in higher fishes they are without exception on the lateral or upper plain of the head; besides, the well-developed nasal capsules of the Selachii are reduced to quite flat pits in *Amia* and in the bony fishes.

A structure homologous with the nasal alar cartilage of the Selachians is entirely wanting in *Amia*, but can be pointed out, as demonstrated above, in certain bony fishes.

Still another, not unimportant, difference in the structure of the nasal region in the higher fishes and that of the Selachians is to be recognized in the fact, that in the former articular facettes for articulation with the anterior end of the palatine arch are developed on the inferior aspect of the region referred to.

The characteristic interrupted rostra, occurring in many Selachians, are wanting in the higher fishes, either entirely or are replaced by simple uninterrupted structures, that approach in this respect the rostra of the Notidanides.

The recapitulation of our investigations go to prove that there are several structures in the organization of *Amia* that cannot be regarded

as having been derived through progressive development from existing structures in the Selachii.

To these belong the diverse courses of the ramus palatinus in the Selachians and in the higher fishes, the relations of which cannot be directly derived from one another. Yet it is not improbable that in this case we are dealing with a substitution of very different and appreciable nerve branches, as often happens in fishes.

In most of the plans of structure in the skull of Amia a direct progress in development can be discerned in parts from those that already exist in Selachii ; and it is particularly the Notidanides—the least differentiated of the Selachians—which present the most evident relations to Amia for recognition.

It would be very difficult to specify the distinguishing characters between the cranium of *Amia* and that of the Teleostei. There are but very few characteristics to be found in the skull of *Amia* that could not be found in one or the other of the families of the Teleostei, and these few distinguishing characters are not restricted to *Amia*, but are also found in other Ganoids. In this category belongs the continuate, non-fenestrated, cartilaginous cover of the primoidal skull, in which, among the Teleostei, vacuities are always discoverable, but it has preserved its integrity in the Accipenserides among the Ganoids. A second important distinction is the absence of the supraoccipital in *Amia* and all the other Ganoids, while in the Teleostei it occurs quite constantly. The third distinction—already described above—refers to the course of the olfactory nerve in a direct prolongation of the brain case—is shared by *Amia* with all the other Ganoids.

POSTSCRIPT.—Just as this article had passed into the hands of the printer, I received a copy of the treatise by J. Van Wijhe, "Upon the visceral skeleton and the nerves of the Ganoids" (Netherlands Arch. f. Zoolog., Vol. V., Part III, 1882), in which the cranial nerves of *Amia* are described. I am glad that Van Wijhe agrees with me in all the essential points. I must also state that Van Wijhe has invited attention to the importance of the mucus canals in determining the bones that overlay the skull (*l. c.*, page 228).[47]

[47] Dr. Sagemhel's paper is completed by a *résumé* of the lettering of the figures, or an "Explanation of figures in the plate," but I have omitted this, as the figures are separately described in their appropriate places here.—TRANS.

PART II.

Henricus Franque, doctor of medicine and surgery, published his famous monograph, entitled Amiæ Calvæ, Anatomian Descripsit Tabalaque Illustravit, in Berlin in 1847. The pamphlet form of this unique paper, familiar to all anatomists who have worked upon or are interested in the osteology of fishes, now lies before me. It extends through seven pages, written in Latin, upon the skeleton of *Amia calva*, with references to some of the soft parts; description of figures in the plate, and the plate itself. This latter presents eleven figures, four of which are devoted to the skeleton; Fig. 9 to a scale; while the remainder illustrate various things in the soft anatomy. Fig. 1 is an upper view of the skull, with all the "cover-bones" retained in their normal positions. In Fig. 2 we are presented with a left lateral view of the entire skeleton of a moderately sized fish of this species. Fig. 3 gives an inferior view of a part of the cranium, with the entire hyobranchial apparatus removed.

These figures are all well done, and in a style peculiar to themselves, bold and clear, though lacking in some points of minute detail. Three of these figures have been copied for me by Mr. H. L. Todd, and reduced by photograph for the purpose of adding to this article the figure of the lateral view of the entire skeleton. This will be valuable in showing the general relation and arrangement of the bones.

The excellent article of Bridge[48] is good as far as it goes, but he treats of the skull of *Amia* only, and we still have to resort to other works to study the extremely interesting points in the remainder of the skeleton. Moreover, as Mr. Bridge's paper was published in the Journal of Anatomy, it is not particularly available to a very large number of American workers. Indeed, this valuable periodical is not subscribed for by nearly as many of our libraries and institutions as it should be, nor as it deserves to be. To present a good account of the entire history of the skeleton of *Amia* is the principal object I had in view upon undertaking the present paper. Just previous to Dr. Sagemehl's paper, which constitutes Part I of this memoir, Bridge very truly tells us, in his article, when reviewing all that anatomists had done with the skeleton of this Ganoid up to 1877, that "the cranial osteology of living Ganoids has been hitherto but partially investigated; and even those genera that have been described by the older anatomical writers will abundantly repay renewed investigation now that the researches of Parker, Gegenbaur, and Huxley have thrown so much light upon the morphology of the vertebrate skull."

[48] Bridge, T. W.—The Cranial Osteology of Amia Calva. Jour. of Anat., normal and pathol. Vol. XI, Pt. IV, page 603. Edinburgh and Lond., July, 1877.

"Agassiz,[49] it is true, has given to us an elaborate account of Lepidosteus, and the earlier description of Polypterus by H. Müller[50] has been supplemented by Dr. Traquair's[51] opportune paper; while to Dr. Günther and Prof. Huxley[52] we are indebted for exhaustive accounts of the skeleton of Ceratodus."

"On the other hand, I am not aware that, beyond the more or less brief accounts to be found in John H. Müller's *Vergleichende Anatomie der Myxinoiden*[53] we have any detailed descriptions of Spatularia, Acipenser, or Amia; and the anatomical student who may wish to acquire any complete knowledge of these genera must content himself with the above-mentioned references, or with such facts as he may be able to glean from such anatomical text-books as Huxley's *Manual of Vertebrata*, Owen's *Comparative Anatomy*, or the *Grundzüge der Vergleichenden Anatomie* of Gegenbaur. More especially is this true of *Amia*. The zoological characters of this genus have been described by several Zoologists. Vogt[54] first detected its true position among the Ganoids and removed it from the Clupeoid Teleostei, with which it had been placed by Müller;[55] and Hyrtl[56] and Franque[57] have described the generative organs and visceral anatomy. But I am not aware that there exists any connected account of the osteology of the skull of this genus, or that the skull has been figured."

Jordan and Gilbert place the *Amias* in the order Halecomorphi, and the single species known, the subject of this paper, *Amia calva*, in the only family in the order, Amiidæ. These authors give as the geographical range of this fish the great lakes and sluggish waters from Minnesota to Virginia, Florida, and Texas. In describing the external appearance of *Amia calva*, they state that it is of a "dark olive or blackish above, paler below; sides with traces of dark reticulate markings; lower jaw and gular plate often with round blackish spots; fins mostly dark, somewhat mottled. Male with a round black spot at base of caudal above, this surrounded by an orange or yellowish shade. In the female this spot is wanting."[58]

On the 12th of February, 1883, I took in a seine near New Orleans, La., four specimens of *Amia*. Two of these were alike; they were very dark above, the ocellation at the base of the tail, large, very black, and the emargination a brilliant buff color. But what was still more strik-

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[49] Agassiz, Poiss, Foss, Tom. 11.

[50] *Abhandl, A. K., Wiss.;* Berlin, 1844.

[51] Journal of Anatomy, Vol. IV.

[52] Phil. Trans. 1871; 5 Proc. Zool. Soc. 1876.

[53] *Vergl. Anat. d. Myx.*, Berlin, 1835.

[54] *Annales des Sciences Naturelles*, Tom. XXIV, Heart and alimentary canal figured.

[55] Müller's paper, "*Sur les Ganoides et sur las classification naturelle des Poissons,*" is translated by Vogt in the xxv. vol. Ann. Sci. Nat.

[56] *A. K. Wiss. Wien.*, 1855.

[57] *Amiæ calvæ Anatomia*, Berlin, 1847.

[58] Jordan & Gilbert. Syn. Fishes of North Amer. Bull. U. S. Nat. Mus., No. 16, 1882.

ing, and what differs from Jordan and Gilbert's description, the pectoral and ventral fins in these two specimens were of a bright Prussian green. The two remaining specimens were smaller fish, much lighter in color, being sort of a clay-brown, with the fins of a similar shade, and less mottled than the others, with the caudal ocellation present, only not so large or brilliant.

OF THE GANOID PLATES.

This series of investing bones of the cranium have been so thoroughly described by Sagemehl above, and by Bridge in the Journal of Anatomy, that I shall content myself with a running review of them, with special references to the fine specimen before me, from which I made my drawing. (Plate IV, Fig. 16.)

The most extraordinary thing about Bridge's description is that he seems to have secured a specimen for his dissection, wherein the parietal dermo-plates were in one piece, without any trace of a suture between them. To the united bone this anatomist gave the name of the dermo-supraoccipital, which is commented upon by Dr. Sagemehl in Part I of this paper.

It seems hardly possible that Bridge could have been mistaken in this matter, as he made special search for the sutural trace dividing them, aware as he was of Owen's already having mentioned that two plates occupied the site of his dermo-supraoccipital. Moreover, the sculpturing would be different on a single plate, as the rugosities would radiate from a single center to the borders as they do in the other plates.

In all the specimens that I have examined, including the one before me, these parietal plates, existed as described by Dr. Sagemehl, even to the detail of the suture not terminating in the median line posteriorly as shown in Plate I, Fig. 1, *Pa.* This was the condition found and described also by Franque, who gives a very good representation of a superior view of the dermal plates in this fish. (Plate II, Fig. 7.)

The arrangement in my specimen is precisely the same as in the specimen drawn by this latter anatomist, the right-hand plate extending more anteriorly and the suture between the bones deflected to this side posteriorly. Figure 7 should show, however, more marked serrations of the margins of the bones anteriorly, as they are invariably found to be so in nature.

External to the parietal plates on either side we find a longer and narrower bone, sculptured as the rest, which is the *squamosal.* (Plate IV, Fig. 16, *Sq.*)

Behind the squamosals and parietals, the hinder margins of which form nearly a straight suture across the skull, we find the *supratemporals*, two rather long, triangular plates placed transversely with their blunted apices meeting in the median line (Fig. 16, *S. tp.*). These two plates shut out from superior view the two forked limbs of the posttemporals upon which they rest.

Of all these plates on the superior aspect of the skull the frontals are by far the largest. Posteriorly they articulate with the squamosals and parietals as already described, while on either side they make room for the postorbitals. (Plate IV, Fig. 16, *Fr.*)

Their anterior bodies are separated from the hinder margins of the nasals by a considerable interspace. This is bridged over by a delicate membrane, which is continuous with a similar tissue that extends across the gap between the frontal and lacrymal on either side (Plate IV, Fig. 16, *jn.*). In prepared skulls where this structure is allowed to remain and dry it becomes very thin, and by cutting through it we expose the posterior narial apertures and the primoidal cranium beneath.

The nasals are oval bones that articulate with each other in the median line by means of a markedly dentate suture. Wedged in between them anteriorly we find the azygos and subtriangular ethmoid (Plate IV, Fig. 16, *Na.* and *Eth.*). Upon the outer side of each nasal, in my specimen, there lies a smaller plate, of a spindle-like form, that corresponds to the plate described by Bridge as the preorbital, although its posterior end occupies a point only about half-way distant between the teeth and the anterior margin of the orbit (Fig. 16, *An.*). This author also figures a small ossification below this preorbital, which does not occur in my specimen. Dr. Sagemehl seems to have found a like structure, but attached no significance to it.

Bridge describes the ethmoid very concisely when he says, "The dermo-ethmoid (*Eth.*) is somewhat T-shaped, with its anterior transverse part slightly concave from side to side. It overlies the prenasal process and the premaxillæ. Each end of the transverse part is in contact with the preorbital bone, while the stem of the T passes backwards between the nasals, separating them for about a third of their extent."[59]

The periphery of the orbit is subelliptical in outline, and six of the dermo-plates contribute to its boundary. The upper half of the circumference is formed by the free margin of the frontal, as the vault of the orbital cavity is made by this bone. Its lower half is bounded by the five remaining plates, of which the superior postorbital is the largest, and the rear suborbital the smallest, though the latter contributes the greatest share to the peripheral circumference.

The most anterior bone of this suborbital chain, I call, in common with other anatomists, the *lacrymal*, as it is quite constant in the class, both in the position it usually occupies and its occurrence. The two smaller plates, immediately beneath the orbit, are true suborbitals, and their number and arrangement vary greatly throughout all fishes.

Behind the large triangular *postorbitals*, we find a group of small bone-plates, forming a vertical chain, that fills in the space between these bones and preoperculum (Plate IV, Fig. 16 k, k', k''). These small plates seem to vary in their size, form, and number, for on the opposite

[59] Jour. of Anatomy, July 1877, page 608.

side of my specimen I find but one of them, which is situated just below the squamosal and shaped like the one marked k'' on the right side.

All four of the *opercular bones* are present and thoroughly developed. (Fig. 16, *Op.*, *S. op.*, *I. op.*, *and Pr. op.*)

The *preoperculum* is a long, narrow, crescent-shaped bone, that touches the squamosal above and contributes to the articulation for the mandible below. Only a narrow strip of its external surface, just within the posterior border, along its entire length, shows the sculpturing common to the other bones. Beyond this its surface is smooth, and its anterior border makes a very intimate union with the hyomandibular and symplectic.

The three remaining opercular bones are beautifully sculptured all over their external surface, and remind one not a little of those rugose surfaces as seen in some of the handsome marine shells. Of these bones the *operculum* is by far the largest; it articulates with an elongate facet, placed upon the upper and posterior angle of the hyomandibular. In common with the remaining two of the group, its anterior border is overlapped by the preoperculum. The upper and lower margins of the *suboperculum* are closely applied throughout their entire extent to the opposed margins of the operculum and interoperculum. This element is of a more irregular form than either of the others, its upper border being deeply concave to admit the rounded lower anterior angle of the operculum, while the inferior one is quite straight. Against this last, the base of the *interoperculum* is applied, this latter plate having somewhat the form of an isosceles triangle, with its rounded apex directed below. The inner surfaces of these three last opercular bones are smooth and unmarked by any sculpturing, as their opposite sides are. A rounded ridge crosses the suboperculum obliquely, extending from its upper posterior angle to the lower anterior one. Anteriorly, the extremity of the *maxillary* (Fig. 16, *Mx.*) is bent towards the median line, and articulates in a socket immediately behind the outer end of the premaxillary, being covered over above by the preorbital and lacrymal plates. Its entire lower margin is armed with a single row of thickly set teeth. These decrease in size from before, backwards, and, like the larger ones on the premaxillary are very sharp and gently curved inwards. The hinder half of the upper border of the maxillary supports an additional thin plate of bone, as seen in so many of the Teleostei. This is the *admaxillary*, and its form is very much the same as in bony fishes (Fig. 16, *a*). Both the maxillary and admaxillary are sculptured on their outer surfaces after the fashion of the other ganoid plates described above.

Bridge says: "In comparing the skull of *Amia* with the skulls of certain of the Siluroidei, and notably with that of Clarias, it is interesting to notice that, in addition to the more obvious and less important points of resemblance between the two genera necessitated by the flattened condition of the head and a foreshortening of the prefrontal

region, there is a close agreement between them in the number and relations of their ganoid plates."[60]

Of the Mandible.—A lateral figure of this very complex bone presents us with a partial view of four of the elements that enter into its composition (Fig. 16). As usual, the chief part of the ramus is made up by the *dentary* (Fig. 16 and Pl. V, 17, *D* or *d*). This bone expands behind to articulate with the angular and surangular on lateral view, while internally this expanded part is broadly concave, which concavity is arched over by the splenial. Anteriorly, it meets the fellow of the opposite side in a rather strong symphysis, the two bones developing a single row of powerful teeth. These are of a conical form, curved backwards, and very sharp at the apices. In Fig. 16 is shown where two of these teeth have been shed, and the shallow pits they leave behind them. The row of smaller teeth beyond, as shown in this figure, belong to the splenial or the plates connecting it with the symphysis. Upon lateral view we may also see the angular and surangular to the extent shown in Fig. 16, as well as the ossification marked *z* to be described further on.

The *angular* is the next in point of size to the dentary. Its outer surface is convex and sculptured in the same manner as the ganoid plates, while posteriorly it forms part of the articulation of the jaw.

Above this element we find the *surangular* splint, which is carried up to form the coronoid process, to be tipped with cartilage at its apex.

Bridge, after his careful investigation of the mandible, says, in his paper quoted above, that it "is an unusually complex structure, as each ramus consists of not fewer than fourteen distinct elements. Meckel's cartilage persists as a thin axial band of cartilage. Its distal end is ossified, and forms a small cylindrical mento-meckelian ossicle (Plate V, Fig. 17 of this paper, *mt. mk.*), which lies in a groove on the inner side of the symphysial end of the dentary (*d*). The proximal end of the cartilage is the seat of at least four distinct ossific centers. Of these, three are arranged in a linear series proceeding from the angular extremity of the mandible. These are referred to in the annexed plates [figures] as *a*, *b*, and *c*. Of these the ossicles *a* and *b* form the anterior and posterior boundaries of the articular cup for the quadrate, and are separated from each other by that portion of Meckel's cartilage which forms the bottom of the cup. The bone marked *c* is much smaller than the other two. That part of Meckel's cartilage adjacent to the articular cup is produced vertically upwards and forwards into a well-marked 'coronoid process' (*cr*). The base of this process is the seat of an ossification (*b*) which forms the outer side of the articular cup, and fits into the cup-shaped distal end of the preoperculum. Thus these three bones, *a*, *b*, and *c*, contribute to the formation of the concave articular surface for the quadrate."

[60] *Ibid.*, page 609.

"Hitherto it has been currently stated in anatomical text-books that the mento-meckelian bone at the distal end, and the articular bone at the proximal end of Meckel's cartilage, were the only elements of the mandible really formed by ossification of the cartilage itself, yet in Amia there can, I think, be but little doubt that at least four, and probably five, ossific centers are developed in the axial cartilage. Whether one of the centers *a*, *b*, *c*, and *d* represents the os articulare of the Teleostean mandible, or whether the latter bone is really a compound bone resulting from the coalescence of the persistently distinct elements of Amia, is not very evident; but I am inclined to think that the os articulare is not so simple a bone as it has hitherto been supposed to be. As the Meckelian cartilage is the distal, or ventral half of the first postoral visceral arch, though it may not be possible to point out the special homologies of the mento-meckelian, and the ossicles *a*, *b*, *c*, and *d*, with the ossifications found in the ventral halves of the remaining postoral arches, yet I think that we may roughly correlate those ossicles with the interhyal, epihyal, ceratohyal, and hypohyal of the hyoidean series."

"It may also be that the cartilaginous 'coronoid process' is another instance of the tendency manifested by the first postoral arch to develop forward connective outgrowths, of which the orbitar process and the palato-pterygoid arcade are conspicuous examples in the proximal half of this arch. In addition to the mandibular elements above referred to there are, in addition, several membrane bones. The ossification *a* has a small ganoid plate (*d. a*)[61] attached to it, which appears at the extreme tip of angle of the jaw."

I show in Plate V, Fig. 18, the large triangular splenial *in situ*. This bone does not run out to the symphysis of the rami anteriorly, but is indirectly connected with it on either side through a chain of five very much smaller plate-like bones. These each support a tuft of good, strong teeth, and very much remind one of the dental plates arranged along on the superior aspect of the branchial arches. I am surprised that Bridge did not notice this when he compared the numerous ossifications of Meckel's cartilage with these arches, as the simile is equally striking. Teeth are found also over quite an extensive area on the upper part of the splenial, though here they are very fine indeed (Fig. 18). When the splenial is in position, a large subcompressed conical space is inclosed between it and the outside bones. The base of this cone is directed inwards and forms the opening to the sulcus in question. Both the symplectic and the preoperculum contribute to form the cup for articulation with the mandible, and the quadrate supplies an articular semi-globular head for the same purpose. As already described, the opposed surfaces on the jaw are developed from special ossific centers.

[61]This is the ossicle marked *z* in Fig. 16 of this paper

A large azygos *gular plate* partially fills in the inter-ramal space (Pl. VI, Fig. 20, *G. pl.*). This plate, occupying as it does the same position as the paired structures of similar description in Polyterus, is held to the surrounding bone by the skin and other soft parts. Its anterior end develops an expanded tip, which is connected by stronger ligament to the symphysis of the jaw. Externally, the surface is sculptured like the ganoid plates on the roof of the skull, while its internal surface is quite smooth. The homology of this plate is still unsettled. It has been spoken of as replacing the urohyal. A very long, osseous gular plate is found in the inter-ramal space among the Elopidæ.

Of the Cranium.—So minutely has Dr. Sagemehl described this part of the skeleton of *Amia calva*, that I will here but hastily view the points for examination, and introduce them merely as a recapitulation to fill in my own account of the skull.

To examine the cranium we must take the head of a fresh specimen, remove the shoulder-girdle, all the ganoid plates, and other structures below and laterally that do not belong to it. Then, from a superior view, we have presented us for examination a large, central quadrilateral, cartilaginous track (Fig. 6). At the anterior extremity of this, we see the intermaxillary (*Sm.*); the premaxillary (*Pmx.*), and the prefrontal (*Prf.*). Occupying a lateral and at the same time a mid position we see the postfrontal (Fig. 6 *Psf.*), while it is bounded behind by the *opisthotic* at the outermost angle (Fig. 6 *Jc*, intercalare, Sagemehl, *op. o*, opisthotic of Bridge), just within which, and above it, we find the exoccipital (*Ex*)—this latter is marked *ep. o.* in Bridge's figure, he considering it the epiotic. Behind these two bones we observe in Fig. 6 a segment marked *Ol*, this is the *occipitale laterale* of Sagemehl, and the exoccipital of Bridge. To the rear of this again we find the occipital arches, so well described by the former author in Part I of this paper.

Now, turning the cranium over, we have presented us upon its inferior aspect, for examination (Fig. 2), first, the pair of *vomers* (*vo.*), situated anteriorly; then traversing the basis cranii longitudinally the parasphenoid *Ps.* (*pa.s* in Bridge's figure). An almond-shaped area in the middle of this latter bone is covered by fine teeth, while the anterior thirds of the vomers support others which are very much larger and arranged in a circular group. The vomers and parasphenoid must now be carefully removed; then we have before us the ossifications shown in Fig. 3—the base of the cranium. Proceeding from before backwards, there are the premaxillary (*Pmx.*); the septo-maxillary (*Smx.*); the prefrontal (*Prf.*); the orbito-sphenoid (*Os.*); the alisphenoid (*As.*); the postfrontal (*Prf.*); petrosal (*Pe.*) (the *proötic* of Bridge); the opisthotic (*Jc.*); and the *occipitale laterale* (*Ol.*) spoken of above. The inferior view of the co-ossified occipital vertebræ is also to be seen from this side.

Upon a direct lateral view (Fig. 5) may be seen the premaxillary (*Pmx.*); the septo-maxillary (*Smx.*); the prefontal (*Prf.*); the orbito-

sphenoid (*os.*); the post-frontal (*Psf.*); the alisphenoid (*As.*); the proötic (*Pe.*); the epiotic (*Ex.*); the opisthotic (*Jc.*); the exoccipital (*Ol.*), and the lateral view of the co-ossified "occipital arches" of Sagemehl.

Lastly, viewing the cranium directly from behind (Pl. III, Fig. 13), we may see the opisthotic (*Jc.*); the exoccipital (*Ol.*); the epiotic (*Ex.*), and the rear view of the vertebræ that have co-ossified with the occiput. Should the vomers and parasphenoid be allowed to remain on, these may also be seen upon lateral views.

As the preceding paragraphs give the differences in nomenclature as used by Sagemehl and Bridge, it will be unnecessary for me to remark upon it further in this connection. I will simply say here that from this point on, I propose to adopt the terms employed by the latter author in designating the various bones.

The *vomers* are cleft behind to admit the parasphenoid, while they are united for their anterior thirds by suture.

Near its middle, the *parasphenoid* throws off on either side a lateral wing, which in each case passes upwards in a curve to bound the proötic anteriorly, lying between the foramina of exit for the fifth and seventh nerves, and finally terminates against the postfrontal.

Viewed from below, the united *premaxillæ* form a crescent-shaped bone, that supports a complete single row of sharp, incurved teeth. These are second in point of size of the various teeth found upon this part of the skull; the largest being on the palatines, and the smallest on the posterior margins of the maxillaries, that is if we do not take into consideration those minute teeth found on certain areas of the bones of the mouth. The ascending portion of the *premaxillæ* is carried back between the nasals and the sub-nasal cartilage as far as the frontals, being covered in this situation by the nasals and ethmoid. Each ascending process is pierced near its center by an oval foramen for the passage of the olfactory nerve.

We now come to examine the chondro-cranium proper and the ossifications that take place in it. Removing the bones we have just described, the remaining part, pyramidal in form, has its broad end posteriorly, while it terminates in front in the prenasal process. The cartilaginous vault is unpierced by any foramina, and neither prominent otic or nasal projections exist, as seen in many of the Teleostei. Accommodating itself to the form of the cranium, the brain-box passes between the orbits to have its apical anterior end terminate between the prefrontals against the hinder margin of the lamina perpendicularis, which in turn terminates anteriorly in the prenasal process, referred to above.

The *supraoccipital* is absent and the *basioccipital* is much elongated, owing to the fact that it has appropriated two of the leading vertebræ of the column, the neural arches of which ride it above.

Exoccipitals are well developed, and contribute both to the peripheries of the foramen magnum and the opening for the vagus.

Independent epiotic, opisthotic, sphenotic (postfrontal), and proötic osseous elements are represented in the auditory capsule, but the proötic is the only one that passes through the cranial wall to be discerned upon the inner aspect of the brain-case. The pterotics are absent.

By the proper interchange of the nomenclature, minute descriptions of all these elements are contained in Part I. Bridge's descriptions are also terse and clear. For those who may by chance in their reading wish to compare the investigations and studies of Bridge upon the cranium of Amia, in his article in the Journal of Anatomy, with Part I of this paper, the following table will be found to be useful in the connection, presenting as it does in a concise form a few of the differences interminology employed by these two authors; where the number of the figure is given in parentheses it is reproduced in this memoir.

TABLE.

Shufeldt.	Figures and lettering.	Bridge.	Sagemehl.
Ethmoid	Fig. 1 + (*Eth.*)	Ethmoid	Ethmoideum. (*Eth.*)
Nasal	Fig. 1 + (*Na.*)	Nasal	Nasale. (*Na.*)
Septomaxillary	Fig. 3 + (*Smx.*)	Septomaxillary	Septomaxillare. (*Smx.*)
Premaxillary	Fig. 2 + (*Pmx.*)	Premaxilla	Praemaxillare. (*Pmx.*)
Preorbital	Fig. 1 (*An.*)	Preorbital	Antorbitale. (*An.*)
Prefrontal	Fig. 3 + (*Prf.*)	Prefrontal	Præfrontale. (*Prf.*)
Frontal	Fig. 16 + (*F. or Fr.*)	Frontal	Frontale. (*F.*)
Postfrontal	Fig. 3 + (*Psf.*)	Postfrontal (sphenotic)	Postfrontale. (*Psf.*)
Parietal	Fig. 1 + (*Pa.*)	Dermo-supraoccipital	Parietale. (*Pa.*)
Squamosal	Fig. 1 + (*Sq.*)	Parietal	Squamosum. (*Sq.*)
Supratemporal	Figs. 1, 16 + (S. *t. p.* and *Esc*)	Supratemporal	Extrascapula. (*Exc.*)
Posttemporal	Fig. 1, 16 + (*Sc.* or *Pst. T.*)	Posttemporal	Suprascapula. (*Sc.*)
Exoccipital	Fig. 1 + (*Ol*)	Exoccipital	Occipitale laterale. (*Ol.*)
Basioccipital	Fig. 5 + (*Ob.*)		Occipitale basilare. (*Ob.*)
Epiotic (*Ep. o*)	Fig. 5 + (*Ex.*)	Epiotic (*Ep. o*)	Occipitale externum. (*Ex.*)
Proötic (*Pr. o*)	Fig. 5 + (*Pe.*)	Proötic	Petrosum. (*Pe.*)
Pterotic (absent)		Absent	Absent.
Opisthotic (*Op. o*)	Fig. 3 + (*Jc.*)	Opisthotic	Intercalare. (*Jc.*)
Vomer	Fig. 2 + (*Vo.*)	Vomer	Vomer. (*Vo.*)
Parasphenoid	Fig. 2 + (*Ps.*)	Parasphenoid	Parasphenoid. (*Ps.*)
Orbitosphenoid	Fig. 2 + (*Os.*)	Orbitosphenoid	Orbitosphenoid. (*Os.*)
Alisphenoid	Fig. 2 + (*As.*)	Alisphenoid	Alisphenoid. (*As.*)

A + means other figures than the one quoted in the second column show the same bone similarly lettered.

The mucus canals have been so thoroughly treated in Part I that I will not revert to them again here. In the mandible the single ramal branch commences in the angular element to pass through the dentary for its entire length, to meet the fellow of the opposite side at the symphysis. This branch connects with the system of the rest of the skull, where the angular articulates with the preoperculum, through which latter bone the lateral mucus canal passes, after having traversed the supratemporal and squamosal.

Both the orbitosphenoids and alisphenoids are more or less circular bones. This is due to the fact that during their extension and development they have not proceeded sufficiently far as to impinge upon neighboring osseous elements for the major part of their peripheries. The position of these bones is well shown in Fig. 3, and others.

The alisphenoid develops two processes and is pierced by two foramina. Of the processes, the smaller one arches over the canal for the orbital muscles; the other is the "descending process of the alisphenoid." The larger foramen passes the first division of the fifth nerve; while the outer and smaller one transmits the second and third divisions.

In each orbitosphenoid we see a deep cleft to allow for the exit of the optic nerve from the brain-case. They are supported by the coalesced trabeculæ below, articulate with the alisphenoids laterally, and support the cover-bones above.

The eye-muscle canal; the shallow pituitary fossa; the trabecular groove; the anterior clinoid process or wall, with the ossifications in its substance; the "proötic bridge;" the openings of the carotid arteries; and other structures in this region have all been sufficiently dwelt upon in Part I.

The lamina perpendicularis being in cartilage, *Amia* in consequence lacks the true ethmoid found in *Polypterus.* In referring to the septomaxillaries Mr. Bridge says that "The two ossifications above referred to as forming the antero-lateral angles of the internasal area are peculiar to Amia amongst Ganoids. They lie, one on each side of the prenasal process, and appear to be ossifications in the cartilage of the floors of the nasal capsules; inferiorly they rest upon the upper surfaces of the vomers. There can, I think, be but little doubt that these ossicles (*sep. mx.*) [Fig. 3 and others of this paper *smx.*] are homologous with the paired endosteal ossifications, which are to be found at the distal end of the great prenasal rostrum in the Pike. In fact, if the prenasal region in Amia were produced anteriorly into a rostrum comparable to that of the Pike, these bones would exactly resemble in position and relations their homologues in the latter fish."

"These ossicles would also appear to be homologous with the septomaxillary bone described by Mr. Parker as existing in the flow of the nasal capsules in the Frog; and also with similar bones in the Ophidia. A section carried through these bones and adjacent cartilage in Amia would resemble in all essentials the various sections given in Mr. Parker's paper (Phil. Trans., 1871) on the development of the frog's skull (Pl. X)"

The next step in our dissection is to carefully remove the suborbital chain of bones; the maxillary and admaxillary; and the ganoid plates overlying the nasal and premaxillary regions, then we have exposed in the prepared skull the elements of the

PALATO-PTERYGOID ARCADE.

This is made up of the palatine, entopterygoid, ectopterygoid, with which are associated the metapterygoid, hyomandibular, symplectic, and quadrate. While intimately related to it is the preoperculum, and less so the operculum itself, which latter merely articulates with the hyomandibular. The entire arrangement of these bones in *Amia* is

upon the Teleostean type, and all the elements found in the bony fishes are present.

Mr. Bridge, in his figure (Jour. Anat., 1877, Fig. 6) representing what I here have drawn in my figure 19, has inserted cartilage among the palatine and the several pterygoid bones. This material I have failed to find in this situation in any specimen *of the age* represented in either figure that I have thus far examined.

The *palatine* (Pl. VI, Fig. 19, *Pl.*) is thoroughly well developed and armed with two sets or kinds of teeth; the first of these, and the largest in this part of the skull, form a single row upon the lateral or exosteal portion of the bone in continuation with those on the premaxillæ. Others, very much smaller, are arranged internal to these on the endosteal lamina of the palatine and continue the vomerine series. Anteriorly at its apex the palatine is grooved to receive the inturned process of the maxillary, which is here wedged in between this bone and the premaxillary. The palatine is also in relation in this region with the septomaxillary, vomer, and prefrontal. It possesses the unique character among Ganoids in its relation with the latter bone in being carried in front of its articulation, a condition well known to us among the bony fishes.

The *entopterygoid* forms the major share of the floor of the orbit, articulating by overlapping sutures with the bones it comes in contact with, while its entire buccal surface seems to be overspread with very minute teeth. This latter condition applies also to the *ectopterygoid* (Pl. VI, Fig. 19, *Enpt. Ectp.*), this bone being additionally armed with a row of fine teeth upon its lower border containing the palatine series. It connects the palatine and quadrate but is separated from the metapterygoid by a thin strip of the entopterygoid.

The *metapterygoid* (Fig. 19, *M. Pt.*) is shaped like a fan with its handle, tipped on the end with cartilage, directed upwards toward the orbit. This is the ascending process of the metapterygoid. The fan part terminates in an angle at either extremity; the anterior angle nearly touches the alisphenoid, while the posterior one overlaps the hyomandibular.

So close is the union between the *quadrate* and *symplectic*, that these two elements appear to form one bone. Taken together they are shaped somewhat like a spherical triangle, the lower angle of each being distinct, the symplectic terminating above the quadrate, each to bear an articular facet for the mandible. In the case of the quadrate this is convex and hemispherical, while in the companion bone it is crescentic and concave, being in reality, one-third of the socket of which the preoperculum affords the remaining two-thirds.

It requires severe maceration in order to separate the symplectic from the quadrate, the union almost amounting to true anchylosis.

The *hyomandibular* (Fig. 19, *H. M.*) is obliquely pierced by an elliptical foramen, near its centre for the exit of the facial nerve. Above,

its straight border articulates in an elongated facet in the cartilage over the otic region. Behind, it supports a large circular facet, borne upon a subsessile stem, for the operculum (*ro*).

Its relation with the cartilaginous interhyal and the symplectic agrees very closely with typical Teleosteans.

Bridge seems to be inclined to believe that the angle formed anteriorly by the long axes of hyomandibular and symplectic, which give these bones their directions, may account for the movement forward of the metapterygoid in this Ganoid. In most Teleosteans this latter bone is directly over the quadrate, and not in front of it. In this I cannot agree with him, but attribute the position of the metapterygoid in *Amia*, entirely to its unusual size, as compared with the neighboring bones, rendering it a physical impossibility to assume any other position. This bone in a bass (*Micropterus salmoides*) before me is squarely over the quadrate and rather behind it, whereas the anterior angle formed by the hyomandibular and symplectic is quite as acute as it is in *Amia*, but the quadrate is relatively very much smaller.

Of the hyoidean and branchial arches (Fig. 19).—In this connection I will also describe the extraordinary series of branchiostegal rays in *Amia*.[62] There are twelve of these appendages, articulating through ligamentous attachment, well within the posterior borders of the epihyal and ceratohyal, upon their outer surfaces. They diminish gradually in size from above downward, slightly overlapping each other about half way down the series. The superior and largest has a somewhat different form from the others, being a long ellipse, with a well-marked longitudinal groove close to its upper border on its external aspect. This surface likewise is sculptured all over quite as thoroughly as one of the ganoid plates and in a similar manner. It articulates both with the epihyal and ceratohyal. The sculpturing gradually disappears as we near the middle of the series, through it can be faintly discerned to the very anterior ray. In life, these rays lap each other anteriorly, the set from one side over the set from the other, under the throat, where they constitute a striking feature and unique ornament.

The articulation of the hyoid with the hyomandibular and symplectic, through the intervention of the cartilaginous interhyal with this bone and the epihyal is very similar to the state of affairs as we find it among ordinary teleostean fishes. Holding a mid-position in the arch, the ceratohyal is a strong, well developed bone, bent at an elbow near its middle (Fig. 19 *c. hy*). The arch is completed by the lumpy little hypohyal, borne at its anterior extremity (*H. hy*). No evidences exist of an ossified glosso-hyal.

The basibranchial elements of the branchial apparatus are composed chiefly of cartilage with very little bone; one of the number seems to be

[62] Mr. Bridge seems to have unfortunately secured an imperfect specimen of the mud-fish in this particular, as he affirms that there are but eleven of these rays, that is hardly a good reason, however, for figuring but *ten*.—(Jour. of Anat., July, 1877, p. 609, and Fig. 6, Plate IV.)

better ossified than the others. There are altogether four of them, and they are much compressed from side to side. The arches proper are five in number, the first four being complete, with the usual elements present. They are completely beset with groups of minute teeth, which ride them above, and come off like scales during maceration. The gill-rakers are very small and thick-set.

Mr. Bridge completes his article in the Journal of Anatomy by a very valuable and concise summary. As this occupies but little more than a page, and contains so much, and in such a convenient form, of use in the present connection, I feel quite sure the reader will think me warranted in reproducing it here, and no doubt be thankful for it.

This author says that "In summarizing the result of the foregoing description of the skull of Amia, I would lay stress on the following facts, as having a special bearing on the affinities of Amia to the more highly specialized osseous fishes and to the amphibia.

"I. The possession of a complete chondrocranium, *i. e.* the absence of fenestræ in the cranial roof, as in Lepidasteus and the Pike (Esox).

"II. The existence of a nearly complete series of otic bones, comprising a large pro-otic, with internal plates forming a characteristic "pro-otic bridge" in the floor of the cranium, opisthotic, epiotic, and sphenotic elements.

"III. The presence of two ossific centers, partly exosteal and in part endosteal, forming rudimentary basisphenoid.

"IV. Septo-maxillary ossifications in the subnasal lamina, as in Clarias, Esox, Rana, and Ophidia.

"V. The interorbital prolongation of the cranial cavity, separating distinct, paired ali- and orbitosphenoids.

"VI. The prolongation of the palatine in front of its prefrontal articulation, and the connection of its anterior end with the inwardly curved process of the maxilla.

"VII. The possession of a T-shaped dermal ethmoid overlying the *premaxillæ*, and the close analogy in number and relations between the investing ganoid plates of Amia and those of the Siluroidei, and especially with those of Clarias, as has been previously described.

"VIII. A complete series of opercular bones, a preoperculum anchylosed to the hyomandibular and symplectic bones, an operculum, an interoperculum, and a suboperculum.

"IX. The presence of a jugal bone [admaxillary (*a*)] attached as in Teleostei to the upper edge of the posterior part of the maxilla.

"X. The existence of a mento-meckelian ossicle, as in Spatularia, and of several additional centers of ossification in the proximal extremity of Meckel's cartilage.

"XI. The presence of five accessory dentigerous splenial elements in addition to the normal mandibular splints, as in the young Polypterus and Ceratodus among Ganoids, and in Siren and larval Salamanders among Amphibia.

"In continuing in its cranial structure the anatomical facts expressed in paragraphs I–IX inclusive, Amia differs from all other living Ganoidei, and exhibits distinct and decided affinities to such generalized types of *physostomus Teleostei* as the Siluroidei, Cyprinoidei, &c. On the other hand, in common with all other Ganoids, Amia possesses several points of resemblance with larval and adult forms of Amphibia, especially as regards the structure to which attention has been directed in paragraphs IV, X, and XI."

"Moreover, in the angulation of the mandibular arch, caused by the forward growth of its metapterygoid element, we have a repetition of an arrangement characteristic of the adult frog, and of certain Selachians, Notidanus. But notwithstanding these evidences of widespread affinity it is evident that if, in addition to the above-mentioned facts, we credit Amia with the possession of cycloid scales, non-lobate fins, a nearly homocercal tail, and note the absence of spiracles, the Teleostean affinities predominate; and it may be asked whether, despite certain peculiarities in structure of its generative organs and bulbous arteriosus, the gap between the ganoid Amia and the physostomus Teleostei is not less than need be expressed by ordinal distinction. It may be that just as Polypterus and its near ally of the same family are the sole surviving examples of the otherwise long extinct order of Crossopterygian Ganoids, so the Amiidæ are the sole survivors of those widely-generalized Ganoidei out of which more specialized Teleostei were directly evolved."

Now, if it were my intention to carry the comparative studies of the skeleton of Amia further than Dr. Sagemehl has in Part I, I would enter the tempting fields offered by the minute examinations that could be made of other American Ganoids and compare them in every particular with our subject. Then comparisons made with the complete skeletons of *Elops* and *Megalops* would be particularly interesting, and on some future occasions these may be treated as I have endeavored to treat *Amia* in this paper. But to undertake such comparisons here would lead me far beyond the intention and scope of my original plan.

It does, however, fall within the limits of this plan to present here a concise review of the skull and other parts of the skeleton of a well-specialized Teleostean, more particularly the skull. Such a review, it is hoped, with its illustrations and figures, will be valuable, from a comparative point of view, taken in the present connection, as well as forming a groundwork for future studies or the observations of others entering upon the study of the anatomy of fishes for the first time.

Of a Teleostean skull.—For my review of this part of the skeleton of a Teleost and for references to such other parts of the osseous system as I propose to enter upon, I have chosen a specimen of *Micropterus salmoides*. This was done because the large-mouthed black bass is a fish of pretty general distribution in the United States, and consequently

will be more easily available for those who wish to compare my statements with the specimen of the fish before them.

In the adult *Micropterus* we find the entire skull very thoroughly ossified, with the vast majority of the bony elements pertaining to this part of the Telesotean skeleton present. Viewing the *cranium* from above, we have presented us for examination, on its hinder calf, five prominent crests; two on either side and a median one. This latter appears to be developed entirely by the supraoccipital (Plate XI, Fig. 27, *S. O*). If the free margins of the lateral crests were produced anteriorly they would all meet at a point just beyond the supraethmoid. The inner pair of these crests are developed by the parietals (Fig. 27, *Pa.*), and they terminate posteriorly in horizontally flattened processes formed by the *epiotics* (*Ep. O*). On the outer side the crests are formed by the squamosals, which in their turn are completed behind by the *pterotics*, which here are vertically compressed plates (Fig. 27, *Sq. Pt. O*). The crest part of the squamosal is formed of two lamina, between which passes the squamosal mucus canal. A deep sulcus is found between the hinder ends of the parietal and squamosal crests, at the base of which we find a large triangular foramen, covered over in the recent state by membrane, just beyond the squamosal, on either side the crescent-shaped and upper part of the *postfrontal* (*Pt. f*). The mid-region of this aspect of the cranium, and constituting the vault of the orbits, is formed by the broad *frontals* (*Fr.*) with a tolerably distinct suture still visible between them. Here an interesting condition of the mucus canals presents itself. This consists in a large V-shaped covered canal with its convex arc just beyond the crest of the supraoccipital, where it has in the median line a common opening. The limbs of this covered V pass through each frontal, to open on the surface, in elliptical apertures, a little behind the prefrontals. They then tunnel again to open once more directly forward on either side of the supraethmoid and over the surface of the nasals. From our superior aspect we also have a good view of the upper surface of the sculptured prefrontals (Fig. 27, *Prf.*), forming the anterior walls of the orbits. Beyond this the region is occupied by the supraethmoid and upper part of the vomer. It is pierced on either side of the promontory formed by the supraethmoid, by the nasal foramen, and the opening for the olfactory nerve.

Upon a lateral view of the cranium we are to note the deep articular facet for the hyomandibular extending from the postfrontal along below the squamosal crest, and occupying the lateral portion of this bone.

Here we see, also, that the *postfrontals* dip pretty well down on the lateral wall, wedging in between the alisphenoid and proötic (Fig. 27, *As. Pr. O. and Ptf.*). The *opisthotics* occupy their most usual site in front of the exoccipital on either side. Beyond the alisphenoid I find an ossification I take to be the *orbitosphenoid*, it is in contact with the alisphenoid behind, runs down the lateral wall of the cranial cavity, while it forms a prominent ridge traversing forwards on the under side

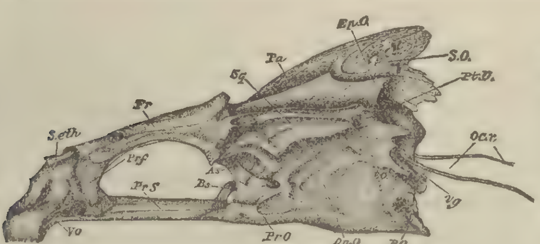
of the frontal. Above each one we observe a canal for the passage of the olfactory nerve from the brain-case to the nasal capsule. The exit for the trigeminal nerve is bridged across by a thin lamina of bone, apparently afforded by the proötic. Another and smaller osseous bridge is found immediately to the rear of this first one. Upon this view the suture between the ex- and basioccipital is plainly visible, while a deep concavity exists in the region through which it is directed.

The *parasphenoid* (Fig. 27, *Pr. S.*), prefrontal, and vomer may also be studied from a lateral view, and the *basisphenoid* is likewise brought into sight. (*B. S.*)

A rear view of the cranium presents most conspicuously among its points for examination the circular and conically concave facet for articulation with the centrum of the atlas. It is developed by the basioccipital and somewhat lower in position than the horizontal plane of the parasphenoid. Above it are two elliptical facets, directed downwards, backwards, and inwards, for articulation with similar surfaces on the first verterbra. Between these exoccipital facets and yet well above them is the foramen magnum, a heart-shaped opening looking downward and backward. The suture dividing the exoccipitals is plainly visible in the median plane of its inferior circumference.

Just above the exoccipital facet, on either side, we find the vagus foramen for the exit of that nerve. Anterior, and at the same time internal to these openings, is to be found a shallow facet, one on each side. These are for the heads of a pair of *occipital ribs* that articulate at these points, and which I have elsewhere described.[63]

The exoccipitals meet just above the foramen magnum, at which point they receive between them the thin lamelliform crest of the supraocci-



Left lateral view of cranium of *Micropterus salmoides*, showing occipital ribs, *Oc. r.* Half size of the original specimen; from author's drawing published in Science (No. 65.) *S. eth*, supraethmoid; *vg.* vagus foramen; and the other lettering the same as figures in this paper.

[63] Shufeldt, R. W. "Osteology of the large-mouthed Black Bass." *Science*, No. 65. Cambridge, May 2, 1884, p. 532. These ribs are of so much interest and at the same time so much importance from a morphological point of view, that I feel warranted in reproducing my original figure of them in this foot-note, illustrating what I have said above in the text. As already announced in *Science*, I have since detected them in the Tunny (*O. Thynnus*) and suspect their occurrence in some of the Scombridæ. It will be interesting for those now engaged in dissecting fishes, or others investigating the anatomy of the class, to be on the lookout for these structures. The family Centrarchidæ should receive particular attention in this regard, and of these the genus *Lepomis* stands among the first to be suspected. Their exact location and constancy should be noted.

pital. The body of this latter bone makes up the major portion of the quadrate surface, upon this aspect of the cranium, contained between the spur-like epiotics and the facets of the exoccipitals. Beyond this surface the pterotics project on either side, in about the same horizontal plane with the superior circumference of the foramen magnum.

An inferior view of the cranium presents principally for our inspection the two bones, *parasphenoid* and *vomer* (Fig. 27, *Pr. S.* vomer not in sight). These, as we well know, are in the adult bass, azygos bones lying in the median plane. The *parasphenoid*, by the assistance of the basioccipital, forms a large oval-shaped surface beneath the canal for the eye muscles; it then contracts again, at which contraction it throws up on either side a plate-like process that has been nearly entirely absorbed by the proötic. The bone beyond this shows another dilation, but not as large as the rear one. It then contracts to form the solid bar that lies between and beneath the orbits (Fig. 27, *Pr. S.*), which anteriorly runs above the vomer and under the prefrontals.

The *vomer* of Micropterus is a very prominent bone. It is carried back well on the under surface of the parasphenoid in a pointed process, the suture between the two bones being easily distinguishable, although this part of the vomer in other respects appears like an extension of the parasphenoid. Anteriorly it forms a beak which is rounded in front, carried well below the general surface beneath, the inferior aspect of this latter part being semicircular in outline and thickly studded with fine teeth.

Of a few of the general points to be noticed about the cranium of *Micropterus*, we have the raised pedicle on the line extending from the prefrontal to the vomer. This pedicle supports an articular facet, directed downwards and forwards, for articulation with a rounded and elevated facet on the anterior end of the maxillary. The bone I have called *supraethmoid* in Fig. 27 is so termed by Parker in his Salmon's skull, because it overlies the cartilaginous ethmoid in that fish; the element is, however, generally termed the ethmoid, or the medium ethmoid (Gegenbaur), and I feel myself at liberty to apply either name to it. The ethmoid is a very proper one. In this bass the proötics form the antero-lateral walls of the eye-muscle canal, but do not meet below in the median line, as they do in some of the Teleostei. Between them in the median line, and springing from the floor of the brain-case, we find a delicate arch of bone, with its convexity directed forwards, that comes down to meet the parasphenoid. This arch belongs to the basisphenoid (Fig. 27, *B. S.*) and is found in many of the bony fishes.

As the relations of many of these bones, described above, on the inner cranial wall, show very well in a vertical, longitudinal section of the cranium of our common American perch (*Perca americana*), I figure such a section here in preference to Micropterus, where the bounding lines or sutures among the elements are not so evident or easily studied.

Some of these cranial bones may be considered to form certain groups, of which *four* enter into the *occipital region.* These are the basioccipital, the two exoccipitals, and the supraoccipital. In *Micropterus*, as in all fishes, the basioccipital is the direct continuation of the spinal column, and possesses many of the characters pertaining to the vertebræ. The *exoccipitals* inclose the aperture of the foramen magnum entirely in this fish, only partly in many others. The supraoccipital, or the upper segment, supports a median crest that corresponds to the neural spine of the vertebra. Its form varies exceedingly, as well as its size. Another group of bones inclose the ear capsule, and have had names bestowed upon them that denote the relative position they bear to it. First and most constant among these is the *proötic;* it is either pierced by or limits the foramen for the trigeminal nerve. Second in order come the *epiotic*, which overlies the superior vertical semicircular canal. It, in the vast majority of fishes, always forms a projecting process. Next we have the *opisthotic*, a segment lying in front and to the side of the exoccipital, but does not appear on the internal aspect of the brain-case nor bear any direct relation with the labyrinth. To these three bones Mr. Parker added a fourth, the *pterotic*, which in fishes forms the postero-external angle of the cranium. In most bony fishes it articulates with the outer limit of the posttemporal. I may add here, in passing, that these bones form the "periotic mass," and are the same found in the petro-mastoid portion of the temporal in man and the other higher vertebrates. It is unnecessary to say more than I already have above about the *squamosal* and *postfrontal.* The latter is sometimes termed the sphenotic, and assists often the former in the formation of the articular facet for the hyomandibular. This is the case in *Micropterus.*

Beyond these, in another group, we have the alisphenoid at the sides and behind and the orbitosphenoids anterior to them, while the basisphenoid is found below. This latter bone, we have already shown in the black bass, forms an osseous partition between the two sets of orbital muscles; it may be absent in some of the Teleostei and very small in others.

On the cranial vault the parietals are not always separated from each other by the intervention of the supraoccipital as they are in *Micropterus*, nor are the frontals always separate bones, they sometimes forming only a single piece, as in *Gadus*. The segments of the ethmoidal region have been sufficiently described above. They all, the prefrontals, ethmoid, and vomer, vary greatly in size, form, and relationship throughout the class.

To still further illustrate the relations that may exist among the bones in crania of osseous fishes, as well as some of the remarkable forms they may assume, I am indebted to Professor Gill for the loan from his private cabinet of the cranium and portion of the palato-quadrate arch of a specimen of *Albula vulpes* and an imperfect cranium of *Megalops*, the latter

being the only one he had in his possession. I chose these two crania, from which I made the drawings that illustrate this essay, because we find in the organization of both *Albula* and *Megalops* at least one feature that they possess in common with *Amia*. In *Albula* it is the peculiar structure of the *bulbus arteriosus* and in *Megalops* the presence of the gular plate. But in describing the crania of these two forms I will confine myself strictly to the two specimens in question, and only describe what is to be seen in them. The sequel will prove that there is much of interest and importance. Judging from the cranium alone, the complete dissection of *Albula* will well repay the anatomist some day, for this part of its skeleton presents many points of the greatest interest and diversity in development.

There is but this one species of *Albula* known to science, and its principal habitat are the warm tropical seas, where it is abundant. With us, however, it has been taken from Cape Cod clear around to Southern California (Jordan and Gilbert.) This fish, we are told by the authors just quoted, possesses "no gular plate."

Viewing the cranium of *Albula* from above, and proceeding with our examination from before, backwards, the first object that strikes us is the extraordinary ethmoid it possesses. (Plate XII, Fig. 30, *Eth.*)

This bone is fashioned off in front so as to remind one very much of the snout of a pig. From this part it extends backwards in a median crest, deeply grooved above. This runs in between two prolongations developed by the frontals, and can be seen opposite the letters Na^2 in Fig. 29. Anteriorly the ethmoid projects over the parasphenoid, which bone abuts against it. From the base of its median crest it sends downwards and outwards on either side a plate-like portion, the margins of which curl up for their posterior moiety. A vacuity of an elliptical outline exists in the crest anteriorly as it reaches the snout-like protuberence, and only the grooved part is carried over to meet this portion of the bone. This foramen can only be seen upon a lateral view as shown in this figure.

The frontals (Plate XIII, Fig. 30, *Fr.*) are very extensive bones and cover nearly the entire superior aspect of the cranium. Their union with the ethmoid is of such a nature as at first to give one the impression that the two are but one bone, and indeed the suture between them is not always discovered at once. Just above the prefrontals, bones which they overshadow all to their outstanding wings, they present on either side of the extension of the ethmoidal crest the openings of two very large mucus canals. These open behind in slit-like foramina, just beyond the letters *Fr.* (Fig. 30), as well as in more minute openings behind and to the outer side of them. The frontals completely overarch the orbits, lap down upon the postfrontals and squamosals, while posteriorly in this specimen the left-hand bone appears to overlie the fellow of the opposite side as well as both the parietals. These latter bones are comparatively small plates of a quadrilateral outline,

with the supraoccipital wedged in between them from behind. The squamosals present quite an extensive surface on superior aspect, and they too have running through them longitudinally, with anterior and posterior apertures, capacious mucus canals. These apertures can be well seen in Fig. 30, the hinder elliptical one just below the letters *Sq.*, and the anterior one opening out over the surface of the prefrontal. (*Ptf.*)

A certain amount of sculpturing is seen upon the surface of the frontals, parietals, and squamosals, in the form of a decided radiation from a central point. This is most perfectly marked in the frontals, where fine radiating lines are carried clear to the peripheries of these bones. A longitudinal depression is found between these latter segments in *Albula*, of a triangular form, being narrow and deep anteriorly, shallow and broad behind. The epiotic and supraoccipital we will reserve for description until we come to deal with the posterior aspect of the cranium of this fish. Fig. 30 shows very well indeed the extent to which these bones may be seen from a superior view of this part of the skull.

The inferior view (Plate XIII, Fig. 31) of the cranium of *Albula* is even more interesting than the superior, owing to the numerous points presented for our examination. This view shows us how far the ethmoid overhangs the parasphenoid, for the narrow, little transverse suture between these two bones is distinctly visible. Just beyond it, on the former bone, we observe a globular protuberance, deeply cleft by a transverse facet, which I take to be the articulation for the upper jaw. Behind this ethmo-parasphenoidal suture the vomer is seen. This bone is shaped like a little fan, the handle being directed backwards in the median line, while the expanded portion lies in the horizontal plane with a rounded margin anteriorly. Within this we find a double row of sockets in the specimen evidently intended for a series of minute teeth. Posterior to the vomerine region the parasphenoid presents a considerable excavation mesially, while opposite this the bone develops, on either side, a horizontal wing-like lamina. Each wing is raised above the general inferior surface of the parasphenoid, being between that bone and the prefrontal behind, while anteriorly it merges into it again. Outside they are bounded by a sharp margin, gently convex throughout.

This aspect also reveals to us again a partial view of the prefrontals (Fig. 31, *Prf.*) with their postero-alar projections. The central point of interest, however, centers about the paraspheroid in this region. It is here broad and elliptical, concave from before, backwards, and slightly so from side to side. An area of teeth occupy this space, conforming to its shape, though separated from its limiting margins all about by some two or three millimeters. These teeth are of various sizes, the smaller ones being arranged all the way round, externally, while they become larger and larger as we approach the mid parts of the space. They are beautifully enameled and rounded. Where the large ones, however, are

crowded together centrally, they assume hexagonal or perhaps pentagonal forms. When they drop out and are lost, they leave quite a deep, conical pit or socket behind them. Posterior to this dental area, the parasphenoid lies horizontally, being convex from side to side, in order to conform with the lower surface of the cranium. Behind, it is forked, the limbs being carried backward to within a millimeter or so of the posterior margin of the basioccipital. Between them we find a triangular depression with its apex directed forward. Viewing the cranium from this aspect, its posterior third is broad and of a quadrilateral outline, the figure being bounded in front by the postfrontals (Fig. 31, *Ptf.*); laterally by the squamosals, and behind by the ex- and basioccipital, opisthotics, and squamosals. Rising in the center of this space, mesially, is the portion formed principally by the proötics and basioccipital, being overlapped by the parasphenoid. This contains the eye-muscle canal, with the braincase above it. Its form is well shown in the figures I present of the lateral and inferior views of the cranium of this fish. On either side of it occurs a deep conical indentation, about which the various foramina pierce the bone to enter the brain-case. These openings, and this great, blind, conical pit are bounded externally by the facet, on either side, for the hyomandibular.

The rear view of the cranium of *Abula* is an exceedingly interesting study, presenting conditions that I have never observed in any other fish. On the superior aspect of the cranium (Fig. 30 *S. O.*) we saw how the supraoccipital was wedged in between the parietals. From this portion in the middle line, it throws backwards and downwards a stumpy, triangular crest, composed for its greater part of two parallel and vertical laminæ, separated from each other by about a millimeter. On either side of this the bone extends horizontally for a little distance to meet the epiotics. These last elements may also be seen upon superior view (Fig. 30 *Ep. O.*). They there articulate with the squamosals and parietals, and with the supraoccipital as just described. Each epiotic from this position, is extended backwards as a stout horizontal and triangular process, a peculiar tubercle being developed on its superior surface. Beneath, and anteriorly, the under surface of this process sends down a vertical plate, lying parallel to the median plane. These two plates inclose a general concavity on the posterior aspect of the cranium, which is partially divided in two by a vertical crest on the supraoccipital which again is directly continued by the crest formed through the uniting suture of the exoccipitals. The upper part of the base of this concavity is composed of the vertical portion of the supraoccipital, while all the lower part is composed of the broad exoccipitals, the cranium being held and viewed with the frontals upwards and in the horizontal plane. Now, wedged in, in this concavity, on each side, and outwards, we observe what first appears to be a separate and nearly circular piece of bone, it being pierced by three foraminæ. Towards the median line it articulates with the supraoccipital and exoccipital,

while externally it meets the epiotic. Careful examination shows that this plate belongs to the *squamosal*. At the base of each vertical epiotic plate is to be seen a stumpy process, formed by a separate segment of bone, which I take to be the *opisthotic*. It articulates with the epiotic, exoccipital, and squamosal. On the outer side of each vertical epiotic plate there is another very deep concavity formed entirely by the squamosal, except such inner part of its entrance which is entered into by the vertical epiotic plate just mentioned. It is near the opening of this deep pit (1.25 ^{cm}) on the inner hand that we have the opportunity to study the manner in which the squamosal furnishes the little circular plate that appears superficially in the larger concavity, as described above.

The *foramen magnum* is of a cordate outline, with its base below. It is directed, that is the plane tangent to its margins, somewhat downwards as well as backwards. Its boundary below is formed by the upper surface of the basioccipital condyle, while its lateral margins and apex are furnished by a bone shaped like a little saddle, which straddles the exoccipitals (Fig. 29, *c. v*). This bone, but loosely united along its median line above, articulates with these last-mentioned segments throughout its entire anterior margin, and in the specimen in my hand is slightly movable. At its lower and outer angles are seen a minute pair, one on either side, of postzygapophyses. This bone fails to come in contact with the basioccipital, and were it removed the foramen magnum would then be formed entirely by the basioccipital and exoccipitals, though these latter would be without articular zygapophysial facets for the first vertebra of the trunk. Dr. Gill expresses the opinion, in which I concur, that this double bonelet is the neural arch of the first vertebra of the column. This being the case, it is importanr to compare it with the co-ossified vertebræ found in this situation in Amia. I would not care to do this, however, until in possession of a recent specimen of *Albula* as well as its young. The outline of the basioccipital condyle is pentagonal, and it is deeply and conically concave. A large elliptical foramen pierces the supraoccipital on either side beneath, at the angle of its horizontal and vertical portion. Two small foramina are also found on either side in the exoccipitals just before we arrive at the suture, where they join the aforesaid free neural arch just mentioned.

This completes my description of the posterior view of the cranium of *Albula*, as far as I mean to carry it. I am well aware that these bones may be differently construed, but the moment we do so it becomes necessary to have the various segments articulate among each other in a manner differing from the general rule they adhere to in the vast majority of cases among teleosts. To satisfy himself of this fact the reader has but to call the bone I have described as a neural arch of the first vertebra, the united exoccipitals, and the result will soon be evident. We must remember, in this connection, that the facet for the

atlas, supplied by the occiput in *Amia*, is upon a co-ossified vertebra. (See Part I.)

Nearly all objects in nature are best seen, studied, and appreciated in direct lateral view, and to this aphorism the cranium of a fish offers no exception. This will at once be recognized in the case of our present subject the "Lady fish," a side view of the parts already examined, which I have endeavored to execute with great care, being presented in Fig. 29, along with the greater portion of the palato-quadrate arch. The shape of the curiously formed *ethmoid* (*Eth.*) is now easily seen, and its relations with its neighboring bones better understood; while beneath it the *vomer* shows but slightly, though enough of it can be observed in order to expose the position of the series of minute teeth spoken of above. The *prefrontal* is seen to be enormously developed. It meets its fellow in the median plane, each one being pierced near this region by a large elliptical foramen. Between the anterior convex border of this bone and the ethmoid we find a vertical lamina of bone articulating as shown in Fig. 29 at *Na*[2]. This element I take to be merely a plate of semi-ossified cartilage, though an examination of *Albula* in the flesh, on some future occasion, may force me to a change of opinion. The true *nasals* in the specimen must have been lost. The orbits are seen to be almost completely separated from each other by a thoroughly ossified inter-orbital septum, an extension forward of the co-ossified *orbitosphenoids*. (Fig. 29 *Os.*) This septum is very materially added to by the broad, vertical plate, afforded by the *basisphenoid* (*ib. B. S.*)

This bone also sends upwards and outwards an osseous limb to articulate with the *alisphenoid* (*As.*). The three sphenoidal bones mentioned surround the optic foramen, as shown in the figure. While the prefrontal completely forms the anterior wall of the orbital cavity, the frontal the vault, the parasphenoid the floor, we find, in addition to the bones we have mentioned, that the posterior wall is largely formed by the *postfrontal* and *proötic*. Altogether this cavity is a very thoroughly circumscribed one, so far as its osseous boundaries are concerned.

The posterior aspect of the postfrontal (sphenotic) assists the squamosal in forming an extraordinarily deep pit in the region to the rear of the upper and posterior angle of the orbit. This pit is bounded above by the squamosal and frontal, anteriorly by the alisphenoid and postfrontal, internally by the squamosal, which bone with the postfrontal forms its floor; behind, it opens along a longitudinal concavity of the squamosal. Immediately below this concavity we find the facet for articulation with the hyomandibular, also formed by the squamosal in part, its anterior moiety being constituted by the postfrontal—not an uncommon condition among the Teleostei.

The regions occupied by the basi- and exoccipital, the proötic and other bones, are so well shown in the figure as not to need any special description here.

We are still further impressed with the marked departures from the ordinary fishes made by *Albula* in its skull when we come to examine such of the bones of the palatoquadrate arch as I have before me, for which I am also indebted to Professor Gill. One view of this arch I have drawn in connection with the lateral view of the cranium (Fig. 29); the other is an inner view of the same specimen, and awarded a separate figure (Fig. 28). When this arch is snugly articulated with the cranium, the *hyomandibular* (*H. M.*) is nearly in contact with the postfrontal and proötic for its entire length, or rather as much of it as is opposite these bones; the same may be said for the remaining elements, the metapterygoidal and entopterygoidal margins meeting the opposed margin of the parasphenoid. Upon an inner aspect this brings the area of teeth found upon the entopterygoid (Fig. 28) opposite and at right angles with the similarly constituted teeth upon the parasphenoid. That teeth should occur exclusively upon the first-mentioned segment is a remarkable fact of itself and worthy of special note. Particular attention is invited to the *symplectic* (*Sym.*) of *Albula*, shown in these drawings, holding as it does a most unique position. Indeed, this may be said of all the bones in this arch; the *metapterygoid* is thrown clear to the rear of the *quadrate*, while in *Amia* it reaches well beyond that bone. Both the *entopterygoid* and *ectopterygoid* are enormously developed. Wedged in between them posteriorly and above is a large mass of bone that appears to be developed on the part of the first mentioned element. Where they meet at the apex anteriorly I find another irregular piece of bone, with a little process on its outer side. This element appears to be separately ossified, but without a complete skull I could not say positively whether it be the *palatine* or not. It occupies about the proper position for that bone, and, everything considered, it would not surprise me to find it assuming any remarkable shape. A highly developed and prominent semiglobular facet is found on the upper third of the posterior margin of the hyomandibular, for articulation with the operculum.

Of the cranium of Megalops.—The specimen of the cranium of this fish is also from the cabinet of Professor Gill, and from it I have made two drawings (Plate XIV, Figs. 33 and 34)—a direct lateral view and a posterior one. The specimen is evidently not a perfect one, though it is the best I could secure for the purpose, and my reasons for choosing it have already been stated above. In this particular specimen the basisphenoid is apparently missing, its median plate having been broken off, leaving the points of fracture distinctly visible. Again, either a single parietal plate or a pair of parietals have undoubtedly been lost, and when perfect individuals come to be examined I believe the space existing in Fig. 34 between the supraoccipital and frontals will be properly filled in by such a plate or plates. The rear view of this cranium is unaffected by these losses, as none of the bones mentioned would come in sight in this aspect.

In *Megalops* the *vomer* is the most anterior bone of the cranium. Viewed from above, it presents a median crest with sloping sides, and is overlapped by a triangular process of the ethmoid. Below it is a broad semicircular plate, with a sharp spine directed backwards, which is mortised into the parasphenoid. Anteriorly this plate supports a raised elliptical disk, armed over its entire surface with exceedingly minute teeth (Fig. 34, *Vo.*). The *ethmoid* throws out on either side a curved and flattened process, directed outwards, downwards, and backwards; against the extremity of each rests an irregular prefrontal (Fig. 34, *Prf. Eth.*). This region is completed by the anterior extremities of the frontal and parasphenoid as far as its bony walls are concerned, while its remaining parts are fashioned in cartilage. The rostrum of the *parasphenoid* makes an angle of 45° with the plane of its body. Its anterior extremity is dilated from side to side, and articulates with the vomer, as already described. The under surface of the rostrum is longitudinally concave, deepest near its middle third. Its upper surface is composed of two sides, each directed upwards and outwards; they meet for the entire length in the median line. The lower part, or body, of the parasphenoid is scooped out above to assist in the formation of the eye-muscle canal; its outer margins articulating with the proötics (Fig. 34, *Pro.*). Posteriorly the parasphenoid is sharply forked, but is not carried backwards quite as far as the basioccipital goes.

The frontals (*Fr.*) are separated bones, divided by a median, and in the specimen rather an open, suture. Behind they overlap the squamosals on either side, while in turn they are beneath the hinder margin of the ethmoid in front. Their posterior margins are scalloped and the superficies of the bones above strongly sculptured. Either *postfrontal* develops a prominent lateral process; the extensive base supporting it so expands as to articulate with the squamosal and frontal above the alisphenoid internally and the proötic below. It also assists the squamosal in forming the anterior end of the hyomandibular facet (Fig. 34, *Ptf.*). A median tubular foramen passes longitudinally through the *orbitosphenoid*, below which it sends forward a peculiar little process as shown in the figure. This is carried backwards as a bony division, separating the alisphenoid, and forming the apex of the margin of the optic foramen. The body of the orbitosphenoid articulates with a cartilaginous plate anteriorly, while its sides, which are tipped upwards, inclose a space which we will devote our attention to further on. The *alisphenoids* are large circular bones, separated from each other by the orbitosphenoid in the median line. They bound the optic foramen laterally and form the posterior wall for the orbits. There seems to be every indication that in life they are separated above from the frontals by cartilage, though they articulate by suture with the postfrontals and proötics (Fig. 34, *As.*).

The *squamosal* is a very large and prominent bone in the cranium of this fish. Above, it forms a considerable share of the vault of the skull,

articulating with the epiotic behind, and the frontal and sphenotic in front. (*Sq.*) Laterally it forms the hyomandibular facet, and enters with the opisthotic and proötic into the formation of a deep conical indentation, immediately below the facet in question. It has a strongly marked and raised ridge, extending from its outer and posterior angle obliquely to the corresponding angle of the frontal (Fig. 34).

The *basioccipital* occupying its usual position, is much compressed from side to side, notwithstanding its centrum behind is very large, with raised periphery. Most of the antero-lateral region of the cranium of *Megalops* is made up of the *proötic* (*Pr. O.*). This bone is pierced by its usual foramina, and meets its fellow of the opposite side in the floor of the cranium. Upon the lateral view of this part of the skull, the most striking feature is a thin lamina of bone, with its plane nearly parallel with the basioccipital, and formed not altogether unlike a diminutive hand. This appendage seems to be developed on the part of the *opisthotic*, but of its function I can say nothing until I am permitted to make a dissection of a fresh specimen of *Megalops*. A *posterior view* of the cranium of this fish reveals to us its most extraordinary structure, and one that would not be suspected hardly from a direct lateral aspect; indeed, not at all, if the vacuity were filled in, where I believe the parietals really belong.

To arrive at a good description of the condition of affairs, as I find them here, it will be necessary for me to describe one or two of the bones seen on posterior view, and first among these the *supraoccipital*. Viewed from above, this bone presents somewhat of an extensive surface, being greatly convex from side to side, while it is carried forward in the median line as a sharp process (Fig. 34, *S. O.*), and behind we see developed a stunted, lamelliform "supraoccipital crest," extending directly backwards, with a small foramen on either side of it. Behind, this bone is represented by a vertical plate wedged in between the epiotics, a vacuity existing at its apex below. The *epiotics* are well shown in Fig. 33 (*Ep. O.*), and the manner in which they articulate with the exoccipitals and squamosals (*E. O.* and *Sq.*). Now upon the anterior aspect the supraoccipital and the epiotic on either side, chiefly the former bone, go to form a plowshare-shaped projection, that forms the hinder and upper part of the vault of the cranium. Beyond it lies a convex surface, in the specimen formed of dried membrane; this constitutes the next section of the *cranial vault*. Upon the outer side of either epiotic we observe a large elliptical opening; these lead into a capacious cavity that exists between the frontals, squamosals, and other bones of the roof above, and the true outer cranial vault, composed of the alisphenoids, prefrontals, squamosals, and other bones below. This cavity is irregularly wedge-shaped, its base being behind and its thin edge situated anteriorly. This latter part lies between the orbitosphenoids below and the frontals above. As we proceed backwards the interspace becomes greater, and it is here bounded by the

frontals above and the alisphenoid and postfrontals below. In this region, too, in the median line, we find that the alisphenoids and orbito-sphenoids contribute to form a bony stanchion, that is directed forwards and upwards for the support of the frontal plates which rest upon its apex. The alisphenoids are produced clear backwards to form a dome-like surface, convex outwards, that is the anterior roof of the cranial vault. In this the alisphenoids are assisted by the postfrontals on either side, and both of these bones can be seen through the apertures of this cavity behind (Fig. 33, *As.* and *Ptf.*). The sides of the roof of the cranium are formed by an incurved surface on the part of each squamosal, while a somewhat similar surface, afforded by either exoccipital, completes the parietes of the brain case in the rear.

The form of the *exoccipitals*, the method in which they articulate with the surrounding bones, and how they contribute to the formation of the foramen magnum, is all well shown in Fig. 33, where these bones are marked *E. O.* A vagus foramen pierces each one on either side of the foramen magnum, while, owing to the fact that the exit for the optic nerves being so large, the parasphenoid can easily be discerned through the latter opening (Fig. 33). The basioccipital forms the lower arc of the periphery of the foramen magnum, as shown in the figure. Its large articular facet is completely covered, through the very interesting fact that it is so far anchylosed with the first vertebra of the column that it is impossible to remove the latter in the specimen without doing it injury (see Plate XIX, Figs. 33 and 34, *c. v.*). This is particularly interesting when we recall what has been said above, in regard to the co-ossified vertebra of *Amia*, found in this locality, as well as the suspicious condition of affairs in these parts in *Albula vulpes*. The suture between this vertebra in *Megalops* and the exoccipital is distinctly retained, and may be traced completely around the bone. Upon the upper side of this co-ossified or rather co-anchylosed vertebra are seen two circular pits, of some little depth and size. Dr. Gill states that these are intended to lodge the extremities of the neural arch. They are placed side by side transversely and about a millimeter apart. Two similar pits and similarly situated occur on the under side of the vertebra. I am unable to pronounce upon these without first examining a recent specimen of this fish.

Far as *Megalops* is removed from *Amia calva*, I still find in this old imperfect cranium from Professor Gill's cabinet plenty of food for thought—with its suspicious-looking basioccipital vertebra, with its appropriation of at least one trunk vertebra, with its *sculptured* frontals and other bones raised above the cranium proper, with its more or less *circular* ali- and orbito-sphenoids, and with the knowledge that a *gular plate* is found between the rami of its mandible.

We now return to our more typical Teleostean, *Micropterus salmoides*, and discuss other bones of its skull that I have as yet not touched upon in this memoir.

As in so many other bony fishes, we find in this Bass a series of irregularly-shaped bonelets, circumscribing the lower boundary of the orbit. These are the *suborbitals* (Fig. 27, *Sb. o.*). They are seven or eight in number, the hinder one resting on the postfrontal, while the large anterior one, which, in common with other osteologists, I have termed the *lacrymal*, overlaps, when in position, the maxillary and prefrontal (*La.*). On either side of the ethmoid, and what at first appears to be almost a continuation of this chain of bones, we observe another slender osseous element. This is the *nasal*. A mucus canal perforates its substance for its entire length (Fig. 27, *Na.*). In designating these bones as the nasals, I am aware it disagrees with what Sir Richard Owen has stated in his Anatomy of Vertebrates in the matter (Vol. I, pages 113 and 114), and must believe with Parker that "the proper nasal (*na.*) is a small ossification on each nasal roof, external to the supraethmoid in its middle region" (The Salmon, Morph. of the Skull, page 74). I must also believe, until some better observer corrects me, that the bone I have described as the ethmoid in *Megalops* and *Albula* is a single ossification in the adult, and the nasals of these forms I take to be missing in the specimens in hand. Resting on the forward end of the cranium in *Micropterus* we find a handsomely developed pair of *premaxillaries* (Fig. 27, *Pmx.*). Each bone has an ascending process in this region of its support, and when the two are properly articulated they form a graceful and nearly semicircular arch, the lower surface of which is thickly studded with very fine teeth. A rounded, lamelliform process is also developed on the upper side of the limb of each premaxillary, about one-third the distance above its pointed extremity (Plate VIII, Fig. 22).

The *maxillary* is a large bone, with expanded hinder extremity, on the upper border of which it supports an *admaxillary* (Figs. 27 and 22*a*). It is completely edentulous as in most other osseous fishes. Anteriorly it does not meet its fellow of the opposite side, but develops at this end, internally a circular and vertical disk, with a raised facet to articulate with the cranium. Another elliptical disk is found at this extremity, directed outwards. It is for the maxillary process of the palatine to play on. The form of the *palatine* in *Micropterus* is well shown in Fig. 22, *Pl.* This bone being firmly articulated with the palato-quadrate arch, and the maxillaries and premaxillaries being freely movable, the mechanism of these latter bones offers an interesting study. The manner in which they may move upon each other is easily seen in Fig. 22. This is still more engaging a subject in those fishes with protractile snouts, of which there are many genera.

In *Micropterus* the opercular group of bones is very well developed (Fig. 27, and Plate XIII, Fig. 32, *Op.*, *S. Op.*, *Pr. O.*, and *I. Op.*). The *operculum* is a beautiful scale-like plate of bone, the largest of the four. In outline it is an irregular quadrilateral, with a reinforced border on its anterior margin, which is so fashioned and strengthened at its upper

and anterior angle as to form a proper enlargement to support the articular facet for the hyomandibular. Viewed from without, its lower border overlaps for a couple of millimeters the *suboperculum*. This latter bone is shaped as shown in Figs. 27 and 32. Anteriorly it develops a pointed and upturned process, that lies between the lower angle of the operculum and the upper angle of the interoperculum.

The *interoperculum* has a quadrilateral outline, with the angles rounded off. Externally it is well overlapped by the preoperculum, and is attached to the mandible by ligament, while internally the epihyal and interhyal of the hyoid arch rest against it. In texture these three bones of the group are semitransparent and exquisitely marked with radiating and wavy concentric lines.

The *preoperculum* overlies all the other opercular bones, while it itself is overlaid by the hyomandibular above and the quadrate below. It is roughly crescentric in form, being carried to a gradually tapering point above, and strengthened throughout its entire length by a raised ridge of bone. On its inner aspect the lower limit of the hyomandibular, the interhyal, and the symplectic rest against it (Fig. 32).

It has been said that the opercular bones are but modified, or rather transformed, branchiostegal rays.

Situated beyond the opercula we discover another arcade of bones; this consists, from above downwards, of the *hyomandibular*, *symplectic*, and *quadrate*, the chain constituting the *suspensorium*. They connect, in *Micropterus* as in the osseous fishes generally, the cranium with the lower jaw (Figs. 27 and 32, *H. M.*, *Sym.* and *Qu.*). By the intervention of the *interhyal*, the hyomandibular has also suspended from its lower extremity the hyoid arch, and its upper and posterior angle, as we saw above, also articulates with the operculum. The hyomandibular is compressed from side to side, expanded above, to be gradually drawn down to a blunt point below, where it is united through a common cartilaginous bridge with the apices of the interhyal and symplectic. This latter element is wedged in between the quadrate and preoperculum, with the metapterygoid resting against its anterior border, it being merely a small bone that has been segmented off from the hyomandibular.

The *quadrate* is here, as is usually the case among fishes, a triangular bone of some size, articulating with the mandible at its lower angle (Fig. 27, *Qu.*). Against the upper half of its anterior border, by a very close suture, the ectopterygoid is placed, forming a part of the connection of the next arch beyond with the suspensorium. Upon the cranium the hyomandibular articulates with the postfrontal and squamosal in a long, narrow, longitudinal facet.

The arch next beyond the suspensorium is the *pterygo-palatine arch*. It is made up of the *metapterygoid*, the *ento-* and *ectoptergoid* and the *palatine*. This last element I have figured and sufficiently described above. In a great many fishes the palatine is movably connected at

the anterior extremity of the arch to which it belongs. The *metapterygoid* (Fig. 32, *M. Pt.*), a flattened and irregularly shaped bone is wedged in between the hyomandibular and quadrate, and firmly establishes the connection of the two arches at this extremity. It overlies also a thin scale-like process thrown out on the part of the *ectopterygoid*, just opposite the angle this bone makes above its articulation with the quadrate. The *ectopterygoid* is a bent and narrow strip of bone that directly connects the quadrate with the palatine. It forms the outer margin of the floor of the orbit, which is chiefly made up of the entopterygoid. Both the palatine and ectopterygoid support a dense area of very fine teeth upon their lower surfaces. The *entopterygoid* is a beautiful shell-like bone which is overlapped by the palatine anteriorly and the metapterygoid behind. It is bent upon itself at about its lower third towards the median plane, and thus forms the greater part of the floor of the orbit by its upper surface, and by its lower the roof of the mouth. The entopterygoid is quite transparent, and for some little distance from its outer margin marked by wavy and delicate concentric lines.

Although the bones just described are so intimately connected with the quadrate, I prefer to call this arch, as I have done above, the pterygo-palatine, considering the quadrate as the property of the suspensorium. It is often termed, however, the palato-quadrate arch, and I took occasion to use this term in the first part of this paper.

Of the Hyoid and Branchial Arches of Micropterus.—Our large-mouthed black bass offers us very little that differs from the more typical Teleosteans in the skeletal parts of its respiratory apparatus. From the lower end of each hyomandibular there is, as we saw above, suspended a small rod of bone, the interhyal (the stylohyal of many authors) To these is articulated, on either side, a broad triangular piece, the *epihyal* (Fig. 32, *E. hy.*), which in its turn connects with the larger and longer piece, the *ceratohyal*. The connection between these two latter elements is very much strengthened by a longitudinal lashing of bony fibers on the inner aspects over the joint, the bones themselves being quite compressed and flattened plates of a form shown in the figure. The ceratohyals, the anterior pair, meet in front in a ligamentous symphysis, over which ride, side by side, two other separate elements, the *hypohyals* (*H. hy.*). These are broadly conical in form, with their apices drawn out into blunt processes, which are directed upwards and backwards. Resting upon the hypohyals above is an azygos bone about a centimeter long (in a bass that would weigh three pounds), which is the *glossohyal* (Fig. 27, *G. hy.*). It is a flattened bone, shaped somewhat like the vertical section of an hour-glass, it being the part of the skeleton which supports the soft parts of the tongue. This bone has also been called the *os linguale*. It may be absent in some of the true bony fishes.

In the specimen I have in my hand we see on the outer aspect of the epihyal, just above its lower and near its anterior border, two large and

curved branchiostegal rays, which in life are held in this position by ligament. The hinder and larger one is possessed of quite a blade-like extension, and the bone, like the rest of the series, is gently curved upwards. Two more branchiostegal rays are attached in a similar manner to the ceratohyal, the four bones being placed at about equal distances apart. The series of branchiostegal rays progressively increase in size from before backwards, the anterior ones being the most abruptly curved. The next two rays in order are attached to the lower margin of the ceratohyal, and I am under the impression that I have dissected specimens where a seventh ray has existed that was attached in order, beyond these, just within this border. As we know, the branchiostegal rays support a membrane of the same name, which forms sort of an auxiliary gill-flap.

Lying in the median plane, posterior to, but attached by ligament to the symphysis of the cerato-hyals, we find a plate of bone, that in the living fish separates the sternohyoid muscles. This bone is of a triangular outline, with its apex forward, a part of which bears a dilatation and *superior osseous loop* for a greater ligamentous attachment. Its lower margin is transversely expanded, and the plate is further strengthened by the development of an osseous rod that runs longitudinally through its center. This azygos plate is the *urohyal*, and is peculiar to fishes. In life it lies between the sternohyoid muscles, and is not always present where a glossohyal exists.

Aside from this *urohyal* and the branchiostegal rays, the bones we have been thus far examining constitute the *hyoid arch*, and this Bass presents it in what may be said a typical form for fishes, if anything can be adopted as a standard in form in a class where all the structures vary so in shape.

The relation of the various bones of the piscine skull and their functions, when we come to compare them with the homologous elements in the higher animals—man, for instance—has always presented to my mind one of the most interesting subjects in anatomy. Here in our specimen we have the hyoid arch, supporting, on either side, a series of branchiostegal rays. *These rays constitute the skeleton of an organ of defense to the respiratory apparatus.* It is believed by some that the opercular bones are modified branchiostegal rays, and these in their turn form the *lateral osseous wall of defense to the gill chamber, also the respiratory apparatus.* The *operculum articulates* with the hyomandibular of the suspensorium, which bone is said to be the representative of the *incus* of the human *ear*, while the lower bone, the *quadrate*, of the suspensorium, is a segmented portion of the *malleus*, another of the auditory ossicles in man. Now, in its turn the quadrate articulates with the *mandible* or lower jaw, a bone in one way subservient to the *digestive* apparatus.

Lying in the angle formed by the limbs of the hyoid, we find the branchial arches. The arrangement of these in *Micropterus* is so like it

is found in *Perca*, and the arches in this latter fish have become so well known both to layman and ichthyotomist, through the many reproductions made of Cuvier's old figure, that I have not thought it necessary to present a figure of this part of the skeleton to illustrate our subject. In the specimen of the bass in my hand, I find but *two* of the copulæ or basibranchials ossified. We remember that three of them ossify in the perch. Then follow on either side the five pair of segmented branchial arches common to the vast majority of the class; these bear the dentigerous patches on their upper surfaces—the gill-rakers being found farther back and on the outer pair only—while below they support the gills proper.

My collection contains specimens, however, where all three of the basibranchials are well ossified, and teeth appear on the upper surface of the rear one in two circular patches. The ultimate gill-raker is T-shaped, the horizontal bar being applied to the outer side of the arch.

The outer pair of branchial arches are each in two segments—a long, posterior, and inferiorly grooved pair, and an anterior or shorter pair that articulate with the middle of the indented sides of the mid-basibranchial. These latter are bent at a right angle, the long limb being continuous with the hinder segment; the short one, which is quite broad, is the part that meets the basibranchial. This description answers very well for the second branchial arch. The anterior segments of the third arch are much broader, and lie on either side of the ultimate basibranchial, while the fourth arch has no anterior segments; the posterior ones, or those that correspond to them in the other arches, touch each other in the median line.

The *infrapharyngeal bones* are broad, thickly studded with teeth on their superior surfaces, and drawn out into sharp extremities behind. Supported in the usual manner through the means of ligaments by the upturned portions of the arches, and lying beneath the cranium—the *suprapharyngeal* bones—are also thickly beset with teeth.

OF THE MANDIBLE OF MICROPTERUS.

We saw that the lower jaw of *Amia* ossified on either side from quite a number of centers; that it developed a large splenial and other separate elements. This is not the case, however, with the large-mouthed black bass. In this fish, as in many other Teleosteans, each ramus is composed in the adult of but three distinct pieces. These are the *dentary*, the *articular*, and the *angular* (Plate III, Fig. 15, *D. Art.* and *Ang.*). Owen tells us that "in both Sudis and Lepidosteus there is superadded a small bony piece, answering to the surangular of Reptiles." (Anat. Verts, vol. i, page 123.)

The *articular* of Micropterus (*Art.*) consists of a vertical and a horizontal portion, the latter being attached to its posterior half, and is extended backwards to bear the concave lunar facet to articulate with the quadrate. The articular surface of this facet, although on the hori-

zontal portion, of course, looks almost directly upwards. The upper aspect of this plate is marked by wavy lines, five or six in depth, that run round the bone parallel to its outer margin. Passing obliquely through the center of the bone is a mucus canal, the posterior opening of which is a circular foramen placed at the back of the articular process. The anterior opening is flattened and is opposite a similar canal that passes through the body of the dentary. The vertical portion of the articular is of a triangular form, and contains, in a canal in its substance, open on the inner aspect, running longitudinally at its base, the Meckhan cartilage (Fig. 15 *M.c.*). This cartilage passes into the dentary which ensheaths it nearly to the symphysis. The posterior border of the vertical plate of the articular is re-enforced by a thickened and raised rim, the laminated portion being beautifully marked by white lines running parallel to its superior margin. Radiating lines are also carried out to this border from the angle formed by its thickened posterior border and its line of union with the horizontal portion.

The inner posterior angle of the horizontal portion of the articular is completed by a separate piece of bone. This is the *angular*. It is triangular in form and unites with the articular in a roughened suture. This union is not so firm but that the piece comes away during ordinary maceration.

The two *dentary* pieces join each other anteriorly in the median plane in quite a firm symphysis. Thus formed, the entire bone constitutes the major part of the mandible, its superior border being thickly studded with rows of teeth. These rows become fewer in number, and the teeth progressively smaller as we proceed backwards, and they cease to appear within short distance of the posterior projections behind. Each dentary element, posteriorly in the vertical plane, is deeply notched by a triangular indentation (Fig. 15). At the anterior apex of this triangle enters the Meckhan cartilage. The limb below, of this fork, lies in the horizontal plane, constituting the hinder half of an elliptical plate of the dentary, similarly situated. It is through this part that the mucus canal is ensheathed, and into it on the inferior surface open three foramina placed a short distance apart. Other foramina pierce each dentary element on the outer aspect, half way between the symphysis and the apex of the postero-superior process. They are for the passage of vessels and nerves.

Huxley, in speaking of the mode of development that takes place in this region, tells us that "two ossifications commonly appear near the proximal end of Meckel's cartilage, and become bones movably articulated together. The proximal of these is the *quadrate* bone found in most vertebrates, the *malleus* of mammals; the distal is the *os articulare* of the lower jaw in most vertebrates, but does not seem to be represented in mammals. The remainder of Meckel's cartilage usually persists for a longer or shorter time, but does not ossify. It becomes surrounded by bone, arising from one or several centers, in the adjacent

membrane, and the *ramus of the mandible* thus formed articulates with the squamosal bone in mammals, but in other *vertebrata* is immovably united with the *os articulare.* Hence the complete ramus of the mandible articulates directly with the skull in mammals, but only indirectly, or through the intermediation of the quadrate, in other *Vertebrata*" (Anat. of vertebrated animals, p. 28, 29). Many of the Teleostei have various muco-dermal bones attached to, or connected with the skull, such as the chain of "supertemporals" that overarch the temporal fossa in some fishes. The most important of these in *Micropterus*, a pair on either side, I propose to call the *supralinear* ossicles (*sl*), as they overlie the anterior end of the lateral line. The largest and most external of these is shaped like a T, the ends of the horizontal portion resting on the squamosal on one hand, and the posttemporal on the other. The vertical limb is directed inwards and a little forwards, having attached to it by ligament the second piece, directed still a little more anteriorly. In the living bass these bones are easily detected, lying just beneath the skin in the lateral line as it arches over the temporal region.

OF THE SHOULDER GIRDLE OF AMIA CALVA.

My description of the girdle of *Amia* will be presented *pari passu* with that of *Micropterus salmoides*, the Teleost we have chosen for comparison in the skull as given above. The nomenclature of the various segments of this part of the skeleton is a matter of great importance, and without entering into any discussion upon this point, I propose here to adopt that of Professor Gill, as set forth in his Arrangement of the Families of Fishes, published by the Smithsonian Institution (November, 1872). Dr. Gill very tersely gives his reasons for departing from the older authors on this subject in the introduction of this valuable and classical paper. It is not necessary for me to repeat his remarks here, as they are now well known to ichthyotomists generally, having been in the hands of scientists for many years.

As the two tables Dr. Gill presents, however, are of great value, and will add so much to my remarks in the present connection, it gives me much pleasure to introduce these here. This eminent ichthyologist first treats of the girdle in Dipnoans, and says in review that "the homologies of the elements of the shoulder girdle of the Dipnoi appear then to be as follows":

Nomenclature adopted.	Owen.	Parker.	Günther.
HUMERUS.	Humerus.	Humerus.	Forearm.
CORACOID (or PARAGLENIAL).	Coracoid.	Scapula.	Humeral cartilage.
SCAPULA.		Supraclavicle.	Coracoid.
ECTOCORACOID (or CORACOID).		Clavicle.	
STERNUM.		Epicoracoid.	Median cartilage.
POSTTEMPORAL.	Scapula.	Posttemporal.	Suprascapula.

In this table I have omitted certain foot notes and quotations connected with it. As to "The Girdle in other Fishes" Dr. Gill remarks

that "the homologies of the elements of the girdle of Dipnoans with those of other fishes, and the added elements in the latter will be as follows":

	Cuvier.	Owen.	Gegenbaur.	Parker.
ACTINOSTS.	Os du carpe.	Carpal.	Basalstücke der Brustflosse.	Brachial.
CORACOID or PARAGLENIAL.		Simple in Dipnoi and Ganoidei.		
HYPERCORACOID.	Radial.	Ulna.	Oberes Stück (Scapulare).	Scapula.
MESOCORACOID.	Troisième os de l'avant bras qui porte le nageoire pectorale.	Humerus	Spangenstück.	Precoracoid.
HYPOCORACOID.	Cubital.	Radius.	Vorderes Stück (Procoracoid.)	Coracoid.
PROSCAPULA.	Huméral.	Coracoid.	Clavicula.	Clavicle.
SCAPULA. ECTOCORACOID.	}	Differentiated only in Dipnoi.		
STERNUM.		Differentiated in Dipnoi.		

POSTTEMPORAL ELEMENTS.

POSTTEMPORAL.	Suprascapulaire.	Suprascapula	Supraclaviculare (*a*).	Posttemporal.
POSTTEROTEMPORAL.	Scapulaire.	Scapula.	Supraclaviculare (*b*).	Supraclavicle.
TELEOTEMPORALS.	Os coracoidien.	Clavicle.	Accessorisches Stück	Postclavicles.

Among Teleosteans, as a rule, the *posttemporal*, a forked bone (Plate VIII, Figs. 23, 24 *Pst. T.*), has its inner limb resting on the epiotic, and its outer one resting against or articulating with the pterotic. In some fishes, as the Cats, this limb comes lower down on the side of the cranium.

The *posttemporal* of *Amia*, although it has on side view (Fig. 24) very much the appearance of this bone in *Micropterus*, this is by no means the case on superior view. In the Ganoid the bone is much spread out horizontally and sculptured for a narrow strip just within its external border, like the "cover-bones" of the skull. Moreover, its inner limb, in *Amia*, articulates with the epiotic, while its outer and lower one, a rounded prong, meets the opisthotic.

The *posttemporal* in *Micropterus* is placed much more in the vertical plane; the anterior extremity of its somewhat compressed and longer upper limb rests on the epiotic, while its lower and shorter limb abuts against the pterotic. A process in both these fishes projects backwards from this fork of the posttemporal, against the inner aspect of which the *posterotemporal* articulates. This latter is a scale like element, with rather a rounded superior head. Its posterior border is deeply notched in *Amia*, and in both cases its flat surface is nearly parallel with the median plane (Figs. 23 and 24, *Psto. T*). Resting on the inner surface of the lower fifth of the *posterotemporal* in *Amia*, we see the upper *teleotemporal* and the superior part of the vertical portion of the *proscapula*. This arrangement is far different in *Micropterus*, where the *teleotemporals* do not come in contact with the *posterotemporals* at all. The *teleotemporal* of the Mudfish is of a quadrilateral outline, and this Ganoid is without any lower *teleotemporal* (Fig. 23 *T.*).

In *Micropterus* there are two of these bones, an upper and a lower one, attached to the other elements of the girdle by ligaments. The upper piece is a scale-like bone parallel to the median plane, while the lower segment is a straight spine resting upon the inner aspect of the entire length of its anterior border (Fig. 23 *T.*). This lower *teleotemporal* was regarded by Carus as a displaced iliac bone. These *teleotemporals* of the bass rest against the coracoids, and above the *proscapula* (Fig. 23). This latter element in *Amia* presents for examination a vertical portion, which has a strong process developed, directed upwards, at its antero-superior angle, a feature it holds in common with *Micropterus*. Now, the outer aspect of this vertical portion is sculptured in *Amia* like the opercular bones, while in the bass it is marked like its own opercular bones, with white, wavy lines and radiations.

The proscapula of *Amia* next sends off anteriorly from its vertical plate, nearly at right angles, a longer and broader portion. This part is pointed at its further end where it articulates with the fellow of the opposite side by ligament. Its upper surface is gently convex, and its inner margin is fortified by a raised rim, directed downwards. This rim, similarly situated, becomes a prominent feature in *Micropterus* (Fig. 23), and the coracoids articulate at its lower edge. They occupy nearly the same position in *Amia*, but here they have become completely amalgamated and are represented only in cartilage (*Yn.*). *Micropterus* lacks a mesocoracoid, but both the *hyper-* and *hypocoracoid* are thoroughly developed. The hypercoracoid is perforated about its middle by an elliptical foramen (Fig. 23, *Hyp. c.*), which is met in many other Teleosteans. Above, this bone articulates with the proscapula, as described above; anteriorly it articulates with the hypocoracoid (*Hyo. c.*), lying in the same plane, while below it articulates with three of the actinosts; the fourth and largest of these bones articulating with the hypocoracoid. This latter bone throws forwards a long, lamelliform spur that reaches far forwards on the under side of the proscapula. It shows a rounded notch behind, just anterior of the facet for the lower actinost. There are *four actinosts* in *Micropterus*, shaped like little dice-boxes, and forming a graded series as regards their size. From their hinder ends spring the sixteen rays that go to form the *pectoral fin* (Plate XIV, Fig. 35, *Ast. Pf.*). I find nine actinosts in the carpus of *Amia*, composed of very elementary bone, with dilated posterior ends, to which are attached the twenty-two rays of the pectoral fin. We cannot see all of these in Fig. 24, because the view does not admit of it, but they are correct in Fig. 35. Delicate markings encircle these rays for their entire length, commencing a short distance beyond their anterior ends.

These members, after passing backwards for about half their distance, divide in two, the forks keeping close side by side and one above the other. This phenomenon is repeated once more before arriving at the posterior margin of the fin. A similar splitting of the fin rays

obtains also in the Mudfish. Here, too, the rays, if maceration is carried to excess, cleave in twain longitudinally, but as this can be studied to better advantage in the caudal rays of this Ganoid, I defer saying anything more about it until that part comes to be described.

In *Micropterus* the apex of the united pelvic bones are inserted posteriorly into the angle formed by the articulation of the proscapulæ. The pelvic bones are situated, as we shall see further on, far back in *Amia*, and differ very much in their general character.

Upon the outer side of each proscapula in *Amia* are found a pair of very curious-appearing scales, composed apparently of a toughened membrane, marked in an irregular manner by lines of semi-osseous material, that require the aid of a lens to properly study. These peculiar affairs are attached loosely to the sides of the proscapulæ, but up to the present writing I am not aware that any physiologist has advanced a theory as to the original function of these appendages. They have no evident use now. In referring to these interesting structures, Dr. Wilder says that[64] "upon each side of the *copula*, or isthmus, which connects the shoulder-girdle of *Amia*[65] with the hyoid arch, there are two appendages which are rarely mentioned by authors, and whose nature appears to be undetermined."[66]

"*Historical sketch.*—According to Duméril,[67] these appendages are what Linnæus referred to in the following phrase, to which zoologists who have spoken of *Amia* do not appear to have attached a definite significance: *Gula ossiculis, scutiformibus, e centro striatus.* Valenciennes supposed that he was impressed by the appearance of the branchiostegal rays, which form on each side a sort of striated plate; but in the phrase cited reference is evidently made to the two small dentated pieces of which I am speaking, and which is easy to see. I have also found them mentioned by Stannius." With further quotation from Duméril, the doctor says, "The appendages are not mentioned in Franque's description of *Amia*, nor in the monographs or systematic

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[64] Wilder, Burt G., on the Serrated Appendages of the Throat of Amia, Proc. Amer. Assn. of Science, 1876, page 259.

[65] *Amia* is a fish found living in the Mississippi River and its tributaries, and in the great lakes. It attains a length of two feet, and is called by fishermen "mudfish," "dogfish," and "lake-lawyer." Under the tip of the lower jaw is a movable plate, which does not exist in any other fresh-water fish of America. The adult male has a circular dark spot at the base of the tail (Jordan, 23, 306). *Amia* is now usually regarded as a ganoid, and its brain closely resembles that of Lepidosteus (the garpike); but it seems to be, as remarked by Gill (10), the "most teleosteoid" of that group. [This foot-note is from Dr. Wilder's article.]

[66] I regret to say that it proved to be impracticable to reproduce Dr. Wilder's figures in his very instructive plate.

[67] I have omitted, in this long but important quotation from Wilder's paper, the figures which this author gives that refer to the bibliographical table at the end of his article. Those who wish to refer to the authorities quoted will have to turn to the Proceedings containing this list. So short is Dr. Wilder's paper, and yet his observations are so valuable in the present connection, that I have incorporated them quite extensively, a fact that the reader no doubt will appreciate.

works of Agassiz, Cuvier, Cope, DeKay, Gill, Günther, Huxley, Jordan, Müller, Owen, Rolleston, or Vogt."

With regard to their location and general appearance, this author states that "in the adult *Amia* there are two appendages on each side. They are usually concealed from view by the operculum; but the tip of the hinder one sometimes projects beyond the operculum at a point a little above the base of the pectoral fin. The anterior appendage is about 2 centimeters long, and its anterior extremity is a little more than half its length from the union of the isthmus with the hyoid arch. Its hinder end is nearly opposite the medium tip of the shoulder-girdle. It is wholly superficial, and its hinder border projects but slightly beyond its attachment. The posterior appendage is about twice the length of the anterior, and consists of three portions: a short triangular *root* just beneath the skin; a short but broad *base*, the deep surface of which is continuous with the skin; a long *free* portion, which gradually tapers backward to the tip, which is less than 1^{mm} wide. The root lies to the mesial side of the posterior extremity of the anterior appendage, but there is a distance of nearly 2^{mm} between them. The posterior appendage inclines dorsad, and rests quite closely against the adjacent surface of the shoulder-girdle.

"Neither has any direct connection with bone. The attached surfaces rest upon the muscles which constitute the isthmus, but do not appear to be attached to them. While observing living *Amias* with reference to their respiratory function I never saw any movement of these appendages. The thickness of the posterior one is about $\frac{1}{2}^{mm}$. It is quite flexible during life and while moist, but becomes more rigid when dried.

"The free surfaces of both appendages are corrugated in the adult. The general direction of the ridges and furrows is across the length of the surfaces obliquely forward from the dorsal toward the ventral border. The ridges are more or less wavy in outline, and present irregularities of direction and arrangement, especially toward the tip and ventral border of the posterior appendage. But the distance between any two ridges is quite uniform; the number of ridges being about 18 to the centimeter upon the anterior appendage, and about 12 upon the posterior. The transverse ridges do not always reach the ventral border upon the anterior two-thirds of the posterior appendage; the ventral third of the surfaces is in some cases nearly free, but may present one or more ridges running nearly parallel with the border, or more often, especially on the inner surface, there may be a series of short ridges trending dorsad and *forward* from the lower border to meet the dorsal series at open angles.

"The anterior slopes of the ridges form an angle of about 45° with the surface; but the posterior slopes are nearly perpendicular. The crests are projected backward as numerous fine teeth which are barely visible to the naked eye."

This author then proceeds to give an interesting account of the development of these appendages, and in the matter of structure says they "consist mainly of fibers running longitudinally. I have not yet examined them under the microscope." The doctor is under the impression he has detected homologous structures in *Lepidosteus*, but as to their function he remarks that "I am not aware that any use has been assigned to these appendages, and I have no suggestion to offer. The anterior is evidently passive. The posterior, even if voluntarily movable by the fish, is too flexible for offense, and is, moreover, covered by the operculum," and with regard to morphological significance "unless some function can be assigned to these appendages the conclusion that must naturally suggests itself is that they are remnants of organs which had greater size and performed some function in more or less remote ancestors of *Amia*. The position and general appearance of the posterior pair are not wholly contradictory of the idea that they may have been accessory branchiæ; but this could hardly be surmised respecting the anterior pair, or the supposed homologous parts of *Lepidosteus*. The appendages should be examined in fossil *Amia* and *Lepidosteus*, and in other extinct Ganoids; likewise should careful search for them be made in all living Ganoids, and in the Teleostean genera *Elops* and *Megalops*, which possess some points of resemblance to *Amia*."

The opportunity has never been offered me to examine either of these latter forms with the view of searching for these structures, and at the present writing I am aware of no one who has thrown any further light upon this subject since Dr. Wilder made the above observations.

OF THE PELVIC BONES AND VENTRAL FINS OF AMIA.

In speaking in a general way of these structures, Professor Huxley remarks, that "In all Elasmobranchs and Ganoids, and in a large proportion of the Teleosteans, the pelvic fins are situated far back on the under side of the body, and are said to be "ventral" in position; but, in other Teleosteans, the ventral fins may work forward, so as to be placed immediately behind, or even in front of the pectoral fins. In the former case they are said to be "thoracic," in the latter "jugular." (Anat. Vert. Animals, p. 39.) These pelvic bones in our subject are quite well ossified, and hold a typical "ventral" position. (Plate X., Fig. 26.) They are in two distinct pieces, each piece being shaped like a paddle, with the blade directed forwards. In life they lie side by side just beneath the skin, with the expanded blades in the horizontal plane. Their anterior extremities are cut square across, while posteriorly they are enlarged so these aspects present an elliptical face in each case. In a specimen of *Amia* with a vertebral column 30 centimeters long, I find the pelvic bones each to measure 2½ centimeters in length. So far as this description goes it agrees very well with these parts, as they are figured and described by Franque, but I find other structures here that apparently are not referred to, in either way, by this anatomist. Now, we discover behind each pelvic bone in *Amia* and articulating with the

posterior elliptical facet described above, another bone of a conical form, and about one-half a centimeter long. This element seems to take the place of the combined actinosts of the pectoral limb. Again, the rays of the ventral fins are arranged in a peculiar manner; these, which seem to number from seven to eight in an adult specimen, are split as they are in the pectoral rays. The ends thus divided are held well apart in order to allow the separate conical piece of bone to be inserted between them. As in the pectorals, too, these ventral fins are "branched" as they approach their posterior terminations. In form each fin is quite acute and the outer ray is the longest.

Among the Teleosts the pelvic bones not only vary in position, but, as we might readily imagine, vary almost infinitely in regard to their relative size and shape. Indeed, it would be a difficult thing to convey any adequate conception in such an essay as this, of these various forms. They are as numerous, nearly, as the species themselves. These bones are never attached to the vertebral column as we find them in vertebrates above fishes. (Owen.)

In *Micropterus salmoides* they are represented by two separate and symmetrical bones, that articulate with each other mesially, by their inner edges. When thus united they form an elongated isosceles triangle, with its apex held by ligament in the entering angle behind the proscapulæ. The outer borders develop a raised rim, and the planes of the surfaces contributed by the two bones superiorly, on either side, look upwards and outwards, the reverse being the case, of course, beneath. The postero-external angles, as well as the hinder border, is thickened and undulating for the articulations of the heads of the ventral fin rays. There is, also, a characteristic process developed mesially on this border, into which each pelvic bone takes an equal share. Above, it is bifid, being directed upwards and backwards, and compressed anteroposteriorly; below, it is peg-shaped and directed in the same degree forwards and downwards.

I fail to find any bony nodules, representing the actinosts, between the ventral fin rays and the pelvic bones in this fish; and the rays themselves seem to be constructed upon the same plan as the pectoral ones, being retained in their positions by firm ligaments and the skin. The outer one, however, on either side, differs materially in form, being spoon-shaped, with the concavity against the next ray on its inner side. It also develops an inturned process, which curves over the next two or three rays. This double arrangement seems designed to strengthen the inner rays, and assist to keep them in their position.

OF THE VERTEBRAL COLUMN, AND SKELETON OF THE REMAINING PARTS.

FIGS. 14, 25, and 26.

Among the general characters of this part of the skeleton we know that "the vertebral column of fishes can only be divided into two re-

gions, the body and the tail. They are distinguished from each other by the characters of the inferior processes of the vertebræ, while the upper arches are connected with the vertebræ in the same manner throughout; and are generally distinguished by the possession of median (spinous) processes. In the region of the trunk, the lower arches are divided into ribs, and supporting transverse processes (parapophyses). In the tail of the Selachii and Ganoïdei they are continuously connected with the centrum, and run out into spinous processes, just like the upper arches." (GEGENBAUR, Elem. Comp. Anat., p 430.) Again, among fishes, generally the vertebræ of the tail develop inferior arches through which the caudal vessels pass. The segments of the column beyond these support ribs which arch over the viscera, but never meet with any sternum mesially, on the ventral parietes. The fins have a skeleton of osseous rays which are supported upon the interhæmal spines.

So well known are they that it is not my intention in the present connection to enter upon the study of the scales of *Amia*. It is sufficient to say that they are of the cycloid type of structure and constitute the exoskeleton of this fish, being arranged much as we find them in the typical Teleosteans.

Anatomists have long understood the morphology of the skeletal parts of the tails of fishes. Professor Huxley tersely presents the conditions for us in these words, when he says that "In all Teleostean fishes the extremity of the spinal column bends up, and a far greater number of the caudal fin-rays lie below than above it. These fishes are, therefore, strictly speaking, heterocercal. Nevertheless, in the great majority of them (as has been already mentioned, page 19), the tail seems, upon a superficial view, to be symmetrical, the spinal column appearing to terminate in the center of a wedge-shaped hypural bone, to the free edges of which the caudal fin-rays are attached, so as to form an upper and a lower lobe, which are equal, or subequal. This characteristically Teleostean structure of the tail-fin has been termed homocercal—a name which may be retained, though it originated in a misconception of the relation of this structure to the heterocercal condition."

"In no Teleostean fish is the bent-up termination of the notochord replaced by vertebræ. Sometimes, as in the salmon, it becomes ensheathed in cartilage, and persists throughout life. But, more usually, its sheath becomes calcified, and the urostyle thus formed coalesces with the dorsal edge of the upper part of the wedge-shaped hypural bone, formed by the anchylosis of a series of ossicles, which are developed in connection with the ventral face of the sheath of the notochord." (Anat. of Vert. Animals, page 131.)

There are ninety vertebræ in the spinal column of *Amia calva;* they are of the amphicœlous type, and devoid of zygapophysial processes (Fig. 14). The centra of these vertebræ are thoroughly ossified, but their

neural and hæmal arches remain free throughout life, articulating with them upon certain facets that are overlaid by their cartilage.

I fail to find a pair of ribs attached to the first free vertebra or what now corresponds to the "atlas." Its neural arch has an independent spine, articulating with it, and directed backwards. A similar spine, only longer, is found in a like position on the neural arch of the second and third vertebræ. Three or four others follow in sequence behind these, but they have no apparent connection with the neural arch of the vertebræ. The second vertebra supports a delicate pair of ribs, which articulate *directly* with the sides of its centrum. In the third segment a small pair of parapophyses have made their appearance, and the ribs of this vertebra articulate with their outer extremities. These parapophyses are characteristic of the vertebræ to the thirty-seventh inclusive. They are always directed downwards and outwards; are longest in mid series, but as they proceed backwards are situated lower down on the centrum of the vertebra. The ribs are long and slender and become more so as we proceed towards the tail; in every case they articulate with the extremity of the parapophyses.

The extremity of the neural spine of the sixth vertebra in *Amia* is bifurcated, and this feature is present for about two-thirds the way down the column; these spines being directed upward and backward, with the ones over the middle of the abdominal cavity more decidedly backwards, though the rear spines are the most deeply bifurcated. Twenty of the ultimate ones are simple in their structure. Not very well marked parapophyses are found upon the thirty-eighth vertebra, and this segment is without a pair of ribs. The neural arches inclose quite a capacious neural canal, and their bases articulate between each consecutive pair of vertebræ, these latter having a form to accommodate themselves to this unique condition (Fig. 26). No neural arch is found upon the forty-fifth vertebra, and from that onwards they only occur upon the alternate segments. In the thirty-ninth vertebra, what would at first appear to be the parapophyses in the anterior part of the column, are here much larger, freely articulated, and inclose a canal by the union of their extremities beneath, in the medium plane. These also skip *the same* vertebra as the neural arches do above them on the column; fourteen of them also support a free spine from their mid points below. After this they are united and pass round the bent-up vertebral column, becoming broader and gradually shorter, where they support the caudal fin rays (Fig. 25). The last six or seven of these *hæmal spines* appear to be anchylosed with the vertebræ.

I count in my specimen before me, fifty-three bony rays in the long dorsal fin; these branch above, and the ultimate ones branch a second time. These rays are supported by an equal number of *interspinous bones*, through the intervention of little ossicles that pass obliquely from one to the other (Fig. 25). All this part has been quite correctly figured by Franque, but this author overlooked a series of delicate little

bones that continue the interspinous bones of the dorsal fin as far as the caudal fin. These are five in number and are seen at *jf* in Fig. 25. The rays of the dorsal and anal fin split longitudinally, as I described them for the pectoral and ventral fins. The anal fin possesses twelve rays in its membrane, and likewise twelve interspinous bones support it, of which the majority in the mid-series have intermediate ossicles as in the dorsal fin. These little bones are each shaped like a dice-box, and not as Franque has represented them in his drawing.

My representation of the skeleton of the tail of *Amia* I have taken so much pains with to secure its accuracy that I believe any verbal description of the parts hardly necessary. (Fig. 25.) More time than usual was devoted to this figure, because the illustrations of this part of *Amia's* anatomy that it has been my pleasure to examine are far from being correct; they are carelessly drawn or simply diagrammatic in character (Kolliker's).

There are twenty-five rays in the caudal fin of this Ganoid. Of these, the two superior ones are very delicately fashioned, the next two are long and slender, while the stoutest ones are found in the middle, from which series they gradually become smaller again as we proceed downwards. In the prepared specimen all of these rays are found to be split longitudinally in the vertical plane, and those chosen from near the middle of the member are found to be branched to the third or fourth division. They are also marked at irregular intervals by raised and transverse divisions. The splitting spoken of allows these rays to seize by their anterior ends the hypural bones coming from the vertebral column, which they do in the manner shown in the figure. In this, the best living example of a masked heterocercal tail, the notochord, being insheathed only in cartilage, has, of course, disappeared in the figure. It is in *Polypterus* that we find nearly the type of what has been termed the "diphycercal" tail, in which the notochord is scarcely bent up at all. Our example of *Micropterus* shows in a marked degree the remaining style of the skeletal parts of the tail in osseous fishes. This is well known to us under the term of the *homocercal* type, and in this fish shows a very completely ossified urostyle, directed upwards and backwards at an angle of about 45°, with a markedly straight vertebral column. The hypural plates are also very broad and perfect in this bass, and the fin rays, very similar in construction with those described for *Amia*, are attached to them in the same manner. As in so many osseous fishes, *Micropterus* has on either side, close to and between the column on the third hypural plate, a sharp, upturned process. This I believe is intended to afford additional surface and leverage for the origin of the muscle that controls the movements of the tail.

In speaking of this part of *Amia's* anatomy Wilder says [68] that "the

[68] Wilder, Burt G., On the tail of *Amia*. Proc. Amer. Association for the Adv. of Science, 1876, pages 264–266.

tail of *Amia* has been figured and described by Franque, Kölliker, and Huxley."[69]

Kölliker's paper is known to me only through the quotations by Duméril. Franque represents only the osseous portions of the skeleton. Huxley gives both form and structure, but not, as it seems to me, quite accurately. Neither of these authors mentions the young *Amia*, or intimates that the form or structure of the tail may vary with age. In discussing the external form this author further remarks that "Dumeril says that the tail of *Amia*, as to its external appearance, differs in no way from that of the ordinary osseous fishes. Its heterocercy, however decided, is well manifested only by the skeleton." Huxley does not allude to the form, but his figure does not very distinctly indicate any difference between the tail of *Amia* and that, for instance, of some Siluroids, where the whole is rounded, and the greatest length is midway between the dorsal and ventral borders."

And, continuing, in the same article he sums up the results of his valuable observations, and says: "I have examined many examples of *Amia*, young and adult, and all manifested the following features:

"1. The greatest length of the tail is considerably above the middle of its height.

"2. The change from the nearly horizontal dorsal and ventral borders to the curved posterior border occurs farther forward upon the ventral side. These features render the ventral slope both longer and more gradual than the dorsal.

"3. When the tail is fully expanded, as while the fish is swimming, the dorsal and ventral slopes meet, so as to form a gentle curve, and not an obtuse point, as in Huxley's figure. This is well shown in (Fig. 3 representing) the tail of a young example in the condition assumed at death.

"The tail of *Lepidosteus* presents the same general features, with some specific variation. Hence, with both these ganoid genera the external form of the tail is decidedly, though not very obviously, unequal."

My interest was first awakened in the structure of *Amia* more than ten years ago, at which time I was permitted to attend Dr. Wilder's lectures at Cornell University, where dissections upon *Amia calva* always held a prominent place. In those days, however, if I remember correctly, Dr. Wilder had made but few, if any, dissections of the young of *Amia*, so it affords me additional pleasure and a peculiar satisfaction to further quote from his paper in the Proceedings his remarks upon the structure of this part of the mudfish's anatomy, supplemented, as it now has been, by studies in that direction. Of it he says that "the terminal caudal vertebræ form an upward curve,

[69] I have, for obvious reasons, referred to elsewhere in this article, omitted Dr. Wilder's number references to his bibliographical table at the end of the above paper in the Proceedings; as well as the references in his text to the figures of his instructive plate.

as shown by Franque. Huxley's figure and description show that the notochord, enveloped by cartilage, extends upward toward the dorsal border of the tail. In all the adults examined by me the termination of this compound rod is considerably nearer the dorsal border than is indicated by Huxley's figure, and presents a rather broad and but slightly rounded tip, with a central depression corresponding to the neural or spinal canal. Here ends the distinct cartilage. Posterior to it, and between the two laminæ of the twenty-first or twenty-second fin-ray (counting from below), is a tract of gelatinous matter, which Kölliker, as quoted by Duméril, seems to have regarded as the prolongation of the notochord. I have been unable to detect any difference between this and the tracts of gelatinous matter between the laminæ of the other caudal fin-rays.

"But that it may fairly be regarded as the prolongation of the notochord, degenerated, and not enveloped by a cartilaginous sheath, is rendered at least probable by the following considerations:

"1. The condition of things in the adult *Lepidosteus*, as described and figured by Kölliker and myself; the notochord with its cartilaginous sheath forming a slender tapering rod, extending between the halves of fin-rays to the junction of the middle and hinder thirds of the tail.

"2. The existence of an undulation of the dorsal border of the tail of *Amia* corresponding with the termination of the supposed notochord.

"3. The greater distinctness of this undulation in young individuals."

This interesting paper concludes with remarks upon "transformation" and "variations in the shape of the tail."

Counting the one from which the urostyle springs, *Micropterus* reckons thirty-two vertebræ in its spinal column, fifteen of which are abdominal. These latter all support each a pair of ribs, which in their turn, all save the last four pair, have epipleural appendages. The atlantal pair articulate with the vertebra at the very base of the neural arch, but as we proceed backwards they gradually recede from this position so as to finally spring from *beneath* the transverse processes on the under side of the vertebra. This condition is characteristic of a great many of the osseous fishes. The neural and hemal arches of this form are completely anchylosed with the vertebral elements, and in the best developed segments, both superior and inferior, post- and prezygapophyses are present.

The arrangement of the osseous fin-rays and interspinous bones in *Micropterus* differs somewhat, to be sure, from the arrangement of these parts in *Amia*, but not at all from what we have known to exist so long in Teleostean fishes, as in *Perca* for example.

Thus we see it is, that although the Ganoid *Amia calva* has in its skeleton many of the characters in common with the highly specialized forms as the Teleosteans, it is, on the other hand, still stamped with characters, more particularly in its vertebral column, of a veritable paleoichthyic type.

LIST OF THE PRINCIPAL WORKS, COMPRISING OTHERS THAN THOSE CITED IN THE FOOT-NOTES, THAT HAVE BEEN EITHER REFERRED TO OR EXAMINED DURING THE PREPARATION OF THIS MEMOIR.

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EXPLANATION OF THE REFERENCE LETTERS USED IN THE PLATES.

[NOTE.—In many instances in Dr. Sagemehl's article the letters in his text do not agree with the reference letters of the figures in his plate; then, again, Franque used a different system of letters, as did the writer. This gave much trouble; but it is hoped that in the explanation of these letters, here given, the references will all be made clear, both for the text and the figures.—R. W. S.]

a. Admaxillary; frontal (Fig. 7, Plate II); also one of the ossifications of Meckel's cartilage (see Plate V, Figs. 17 and 18), and α a ligament between nasal and frontal. [Franque.]

αg. Angular. [Bridge.] (See Plate V, Figs. 17 and 18.) Also *Ang.* (Plate III and others.)

An. Preorbital (Plate IV, Fig. 16); antorbital.

an. Angular (Plate VII).

Art. Articular (P^5, os condyloideum of Franque, Plate X).

As. Alisphenoid.

Ast. Actinosts.

β. Ossa in cutem immissa (Franque), supratemporal of the author

b. Parietal of Franque (Fig. 7).

b. One of the ossifications of Meckel's cartilage (Plate V, Fig. 17).

b. a. Branchial arches.

B. O. Basioccipital.

Brs. R. Branchiostegal rays.

B. S. Basisphenoid.

Bs. b. Basibranchials.

c. One of the ossifications of Meckel's cartilage in Plate V.

c. Os mastoideum (Franque), the squamosal of the other figures; *Sq.*

ca. Carotid foramen.

cb. Vascular canal of the occiput (in basioccipital).

ce. External semicircular canal.

C. hy. Cerato-hyal.

cp. Posterior semicircular canal.

cr. Coronary cartilage (Bridge), Plate V, Fig. 17.

Cs. Anterior semicircular canal.

c. v. Neural arch of first vertebra in *Albula* and the co-ossified first vertebra in *Megalops.*

D. Dentary.

d. One of the ossifications in Meckel's cartilage. (Bridge.) Plate V.

d. Nasal. (Franque.) Pl. II, Fig. 7.

d'. Os alare (Franque); the author's antiorbital, while Franque's antorbital *h* I have the lacrymal.

δ'. Posterior nasal aperture. (Franque.)

e. Ethmoid of Franque. (Pl. II, Fig. 7.)

Ecpt. Ectopterygoid.

E. hy. Epihyal.

Enpt. Entopterygoid.
E. O. Exoccipital. (See also *Ex.*, Fig. 1.)
ep. Epiphysial crest.
Ep. O. Epiotic.
Esc. Extrascapula. (Sagemehl.) Fig. 1.
Eth. Ethmoid.
Ex. Exoccipital. (Sagemehl.)
F. Frontal.
f. Superior maxilla. (Franque.) Pl. X, Fig. 26.
fa. Foramen for exit of facial nerve.
fh. Hypophysial foramen.
g. Intermaxillary. (Franque.)
G. hy. Glossohyal.
gph. Foramen for glossopharyngeal nerve.
G. pl. Gular plate.
h. Antorbital. (Franque.) Pl. II, Fig. 7.
H. hy. Hypohyal.
H. M. Hyomandibular.
hm. Articular facet for hyomandibular.
Hyo. c. Hypocoracoid.
Hyp. c. Hypercoracoid.
i. Infraorbital bones. (Franque.) (Pl. X, Fig. 26.)
ih. Interhyal.
I. Op. Interoperculum.
Jc. Intercalare (opisthotic). Dr. Sagemehl evidently meant *Ic.* to appear on his figures, and this must be a mistake of his engraver.
jf. Continuation of interspinal bones. (Not previously described.)
jn. Membranous tract extending between frontals and nasals.
k. Postorbital. (Franque.) Pl. II, Fig. 7.
k, *k'*, *k''*. Designate, with a small unnumbered piece above them, a disconnected chain of bones, that are sometimes found in *Amia*, between the postorbitals and preoperculum. (Plate IV, Fig. 16.)
La. Lacrymal.
m. c. Meckel's cartilage in Plate III, Fig. 15.
mk. Meckel's cartilage. (Bridge.) Plate V, Fig. 17.
M. Pt. Metapterygoid.
mt. mk. Mento-Meckelian bone.
Mx. Maxillary.
n. Suprascapula. (Franque.) Plate II, Fig. 7.
Na. Nasal.
Na². A semicartilaginous piece of bone found in *Albula vulpes*. Figs. 29, 30.
Ob. Basioccipital. (Sagemehl.)
Oc. I, *Oc. II.* First and second occipital arches of *Amia*. (Sagemehl.)
oc. I, *oc. II*, and *oc. III.* Foramina of exit of the first to the third occipital nerves in *Amia*. (Sagemehl.)
oc. r. Occipital ribs in *Micropterus*. (Shufeldt.)
Ol. Occipitale laterale. (Sagemehl.)
ol. Opening for nasal nerves.
Op. Operculum.
op. Optic foramen.
Os. Orbitosphenoid.
P. Inframaxilla. (Franque.)
P1. Dentary.
P3. Coronoid.
P5. Os condyloideum.

Pa. Parietal.
Pe. Petrosal. (Sagemehl.)
Pf. Pectoral fin.
pl. Dr. Sagemehl gives this in his figures, but not in his list.
Pmx. Premaxillary.
P. Op. Preoperculum.
P. or. } Postorbitals.
P. or[1]. }
Prf. Prefrontal.
Pr. O. Proötic.
Pr. S. Parasphenoid.
P. Sc. or *Ps.* Proscapula (Plate XIV, Fig. 35). *Ps.* Parasphenoid of Sagemehl.
Psf. Postfrontal.
Psto. T. Posterotemporal.
Pst. T. Posttemporal.
Pt. O. Pterotic.
Pv. Pelvis.
q. Operculum. (Franque.)
q^1. Interoperculum. (Franque.)
q^2. Suboperculum. (Franque.)
q^3. Preoperculum. (Franque.)
Qu. Quadrate.
ro. Facet for articulation with operculum.
s. Os pterygoideum externum seu transversum. (Franque.)
Sag. or *S. Ang.* Surangular.
Sb. o. and *Sb. o*[1]. Suborbitals.
Sc. Suprascapula.
S. eth. Supraethmoid.
sl. Supralinear.
Smx or *Sm.* Intermaxilla, septomaxillary.
S. O. Supraoccipital.
S. Op. Suboperculum.
Sq. Squamosal.
S. tp. Supratemporal of Bridge and the author; extrascapula of Sagemehl.
Sym. Symplectic.
T. Teleotemporal.
T^1. Lower teleotemporal.
T^{11}. Teeth.
tg. Temporal fossa.
tr. Foramen for the first branch of trigeminal nerve. *Tr.* For the second and third branches of the same.
v. Foramen for exit of vagus.
V. f. Ventral fin.
vg. Vagus foramen.
Vo. Vomer.
x. Two small pieces of cartilage posterior part of cranium of Amia. (Sagemehl.)
Yn. Coracoid of *Amia* (in cartilage).
z. One of the ossifications of Meckel's cartilage; the one marked *a* in Plate V, Figs. 17 and 18.

PLATE I.

Fig. 1. Cranium of *Amia calva* from above; life size. The dark piece projecting at the lower right-hand angle is the continuation of *Sc.* The little piece at the anterior end of the frontal suture is in cartilage, as is *ol*, and the triangular wedge at the inner end of *Esc.* Sagemehl's original plates have all the cartilage tracts in color, a pale blue. This could not be carried out in the present connection. The lightly stippled and unlettered parts, generally, are in these figures, however, the cartilaginous tracts.

Fig. 2. The same specimen, cranium seen from below.

Fig. 3. The same specimen, the parasphenoid (*Ps.*) and the vomers (*Vo*) having been removed. (These three figures copied from Sagemehl's plates by Mr. H. L. Todd.)

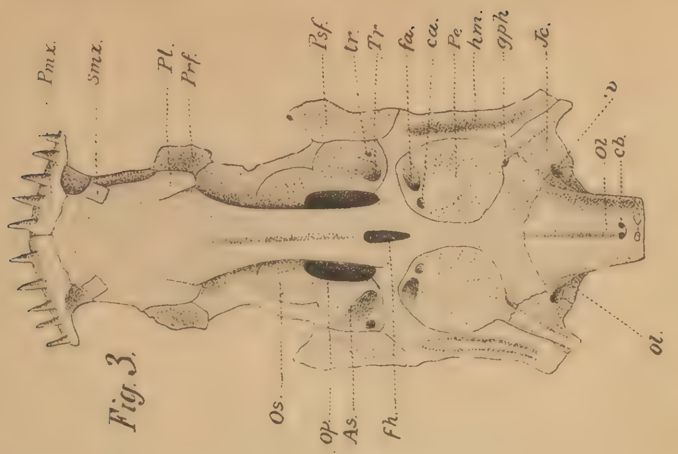


Fig. 3.

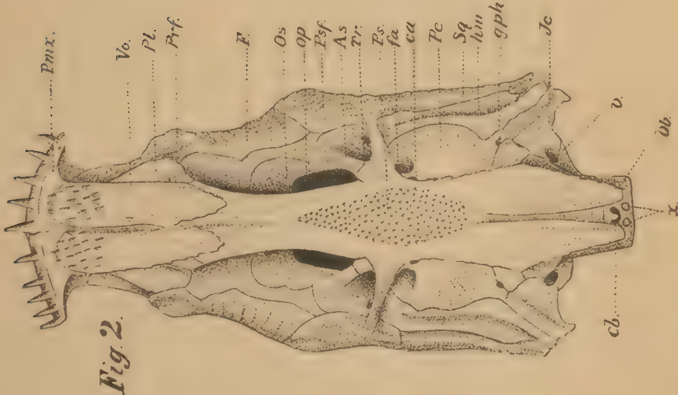


Fig. 2.

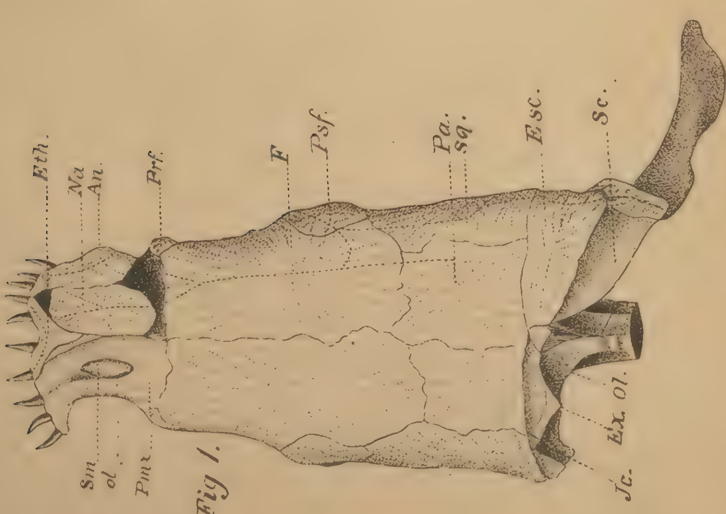


Fig 1.

PLATE II.

FIG. 4. The skull of *Amia calva* vertically bisected through the median line; same specimen; life size. (After Sagemehl.)

FIG. 5. The same; lateral view of the cranium before bisection. (After Sagemehl.)

FIG. 6. Primoidal cranium of *Amia calva;* same specimen as before, viewed from above after the removal of all the "cover bones;" life size. The cartilage tracts here are between the premaxillaries (*Pmx*); at *ol*; all the central portion and the lateral fossæ, *ta*. (After Sagemehl.)

FIG. 7. Superior view of the skull of *Amia calva*, with all the "cover bones" *in situ*. Life size. (After Franque.) The figures in this plate copied by Mr. H. L. Todd from the author's figures as given.

Fig. 4.

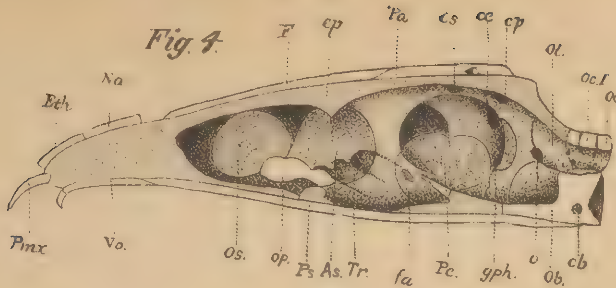


Fig. 5.

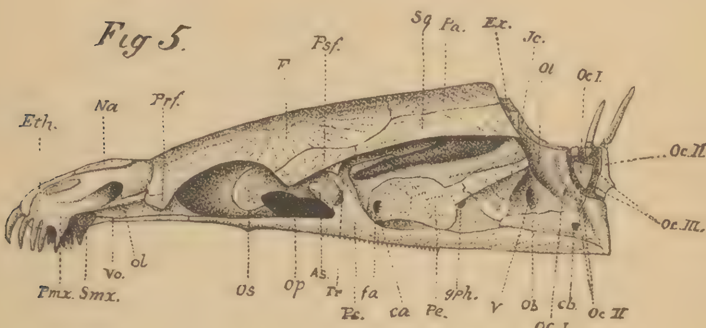


Fig. 6.

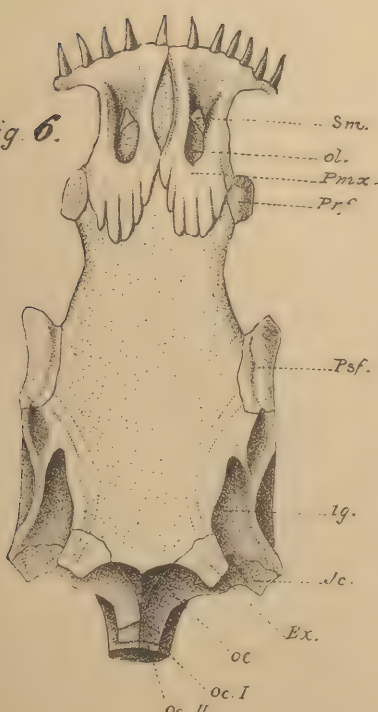


Fig. 7.

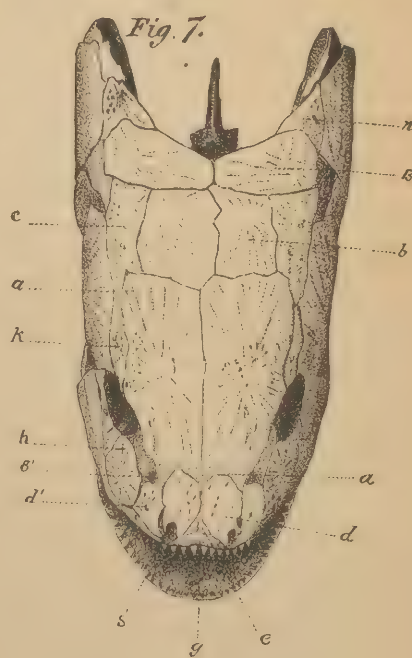


PLATE III.

FIGS. 8 and 9. Transverse sections through the cranium of *Amia calva* in the region of the nasal pits. Fig. 8 the anterior section, and they follow in sequence through Fig. 12. The sections are diagrammatic; with the cartilaginous parts stippled. (After Sagemehl.) Copied by Mr. H. L. Todd.

FIGS. 10, 11, and 12. Similar sections through the region of the optic foramen, the facial foramen, and the labyrinth region just anterior to the foramen for the glossopharyngeal, respectively. (After Sagemehl.) Copied by Mr. Todd.

FIG. 13. Posterior view of the cranium of the same specimen of *Amia calva*. Life size. (After Sagemehl.) Copied by Mr. Todd.

FIG. 14. Three vertebræ of *Amia calva*, magnified about three times, showing the method of articulation of the neural spines and the facets for the ribs. (After Franque.) Copied by Mr. Todd.

FIG. 15. Left lateral view of mandible of a Teleostean fish (*Micropterus salmoides*). Life size. Drawn by the author from his own dissections. The various bones pulled apart to show their entire shape.

Fig. 8.

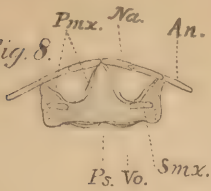


Fig. 9.

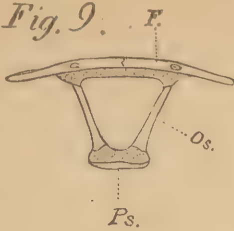


Fig. 10.

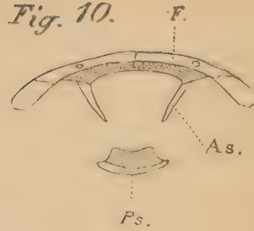


Fig. 11.

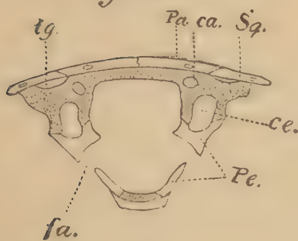


Fig. 12.

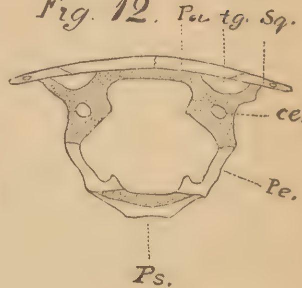
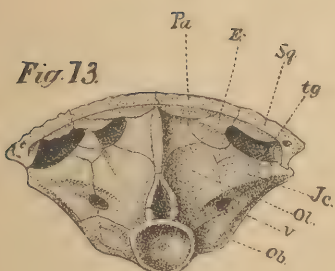


Fig. 13.



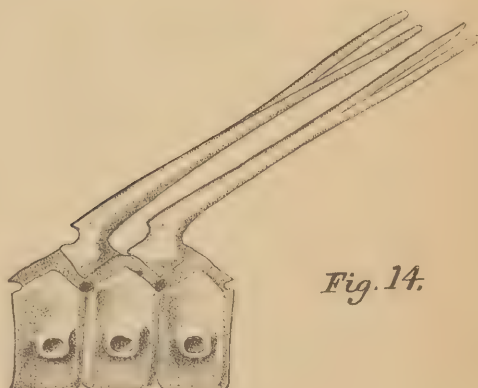


Fig. 14.

Fig. 15.

PLATE IV.

Fig. 16. Right lateral view of the skull of *Amia calva*, showing the arrangement of the Ganoid plates. Life size from nature, by the author. This specimen was collected by me near New Orleans, La., in 1883.


Pmx
Eth
Na
jn
Fr
Ptf
Pa
Sq
S.tp
Pst.T
Psto.T
Op
S.Op
I.Op
P.Op
Por
Por'
Mx
a
La
Sbo
Pt
Ect
Qu
S.Ang
Ang
D

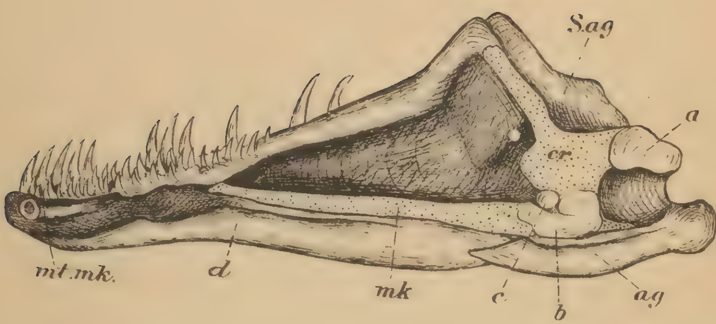
Fig. 16.

PLATE V.

FIG. 17. Inner aspect of the right half of mandible of *Amia calva*, the splenial element removed. (By the author, after Bridge, somewhat enlarged.)

FIG. 18. The same view from a specimen in my own possession; the splenial element *in situ*, together with the bones connecting it with the symphysis. Enlarged. (From nature, by the author.)

Fig. 17.



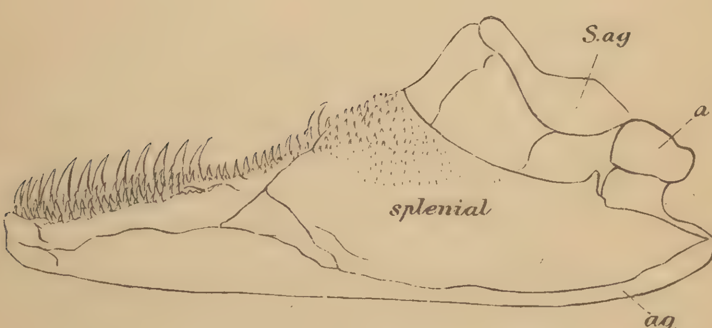


Fig. 18.

PLATE VI.

FIG. 19. The palatopterygoidean arcade of *Amia calva*, together with other associated bones and the hyoidean arch, to the outer side of which articulate the twelve branchiostegal rays, *Brs. R.* The dotted portions about the hypohyal, metapterygoid and epihyal represent cartilage, but all other cartilaginous and membranous portions have been carefully removed. This figure well shows the relation of the hyoidean arch to the other bones represented, as it does the position occupied by the semi-anchylosed preoperculum. Life size from nature, by the author.

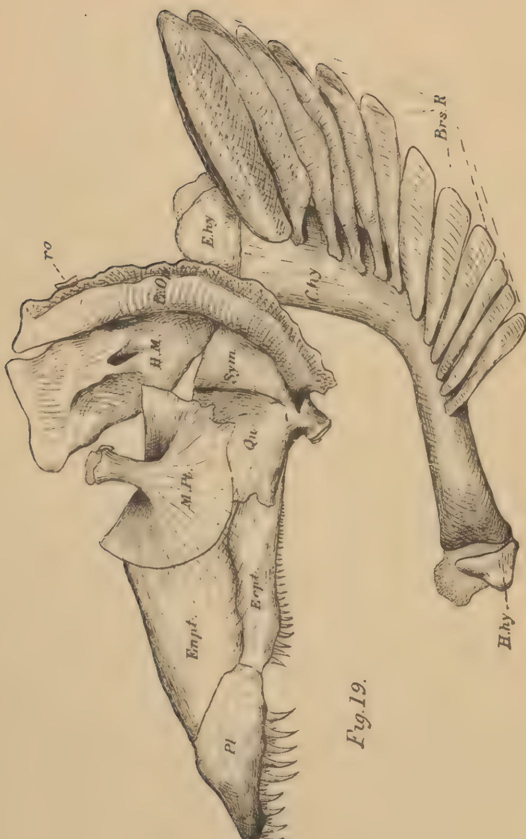
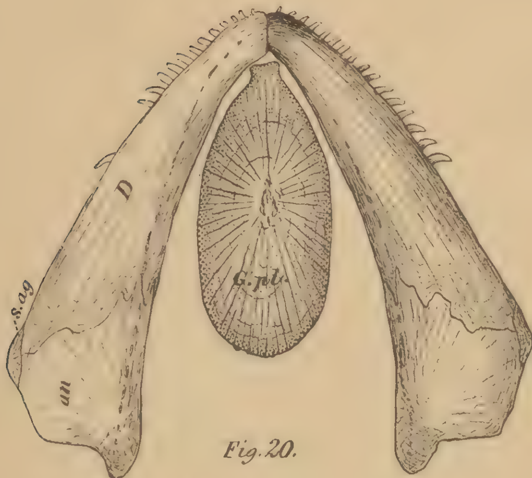


Fig. 19.

PLATE VII.

FIG. 20. Inferior aspect of the mandible of *Amia calva*, showing the normal position of the gular plate, *G. pl.* Life size from nature, by the author.

FIG. 21. A longitudinal, vertical, median section of the cranium of a perch (*Perca americana*), inside view showing the relations of the various bones, the position of the *otolith*, the eye-muscle canal, and the bones that enter into the ear capsule. Adult. Slightly enlarged from nature, by the author, from his own dissections.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S.ag
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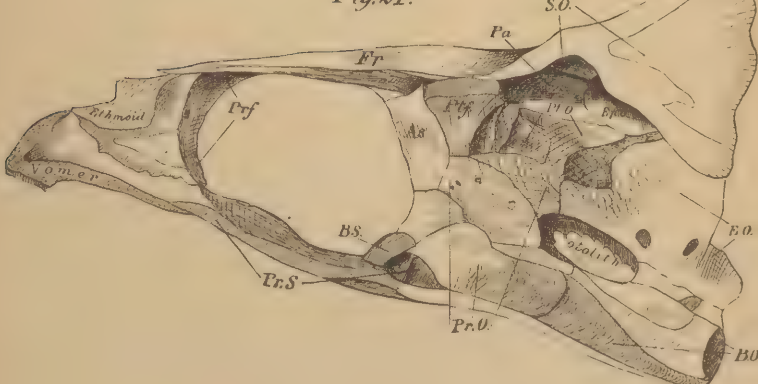
Fig. 20.

Fig. 21.


S.O.
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Prf
Ethmoid
Vomer
As
Ptf
Pt.O
Ep.O
BS.
Tr.S
Pr.O.
otolith
E.O.
B.O.

PLATE VIII.

FIG. 22. The left outer aspect of the upper jaw of a teleostean fish (*Micropterus*), together with the bones associated with it. These latter are slightly dislodged from their normal positions, the better to show their relations. Life size from nature, by the author, from his own dissections.

FIG. 23. Inner aspect of left half of shoulder girdle and pectoral limb of *Micropterus salmoides*.

FIG. 24. Same view of like parts in *Amia calva*. Both figures reduced one-fourth. From nature, by the author.

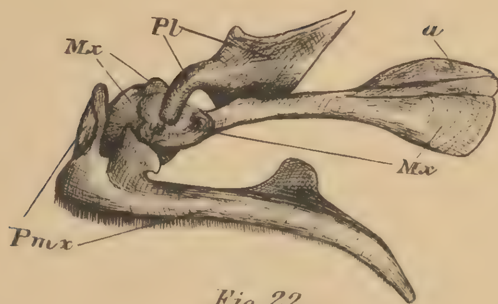


Fig. 22.

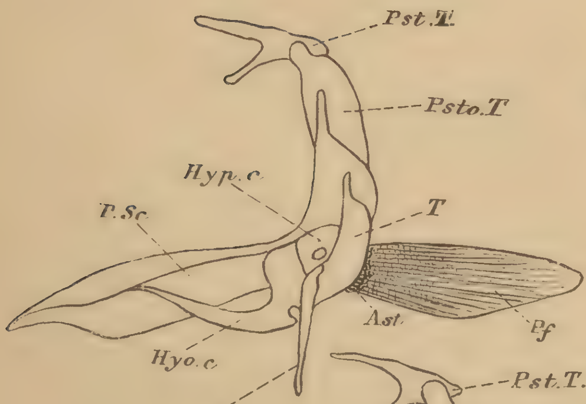


Fig. 23.

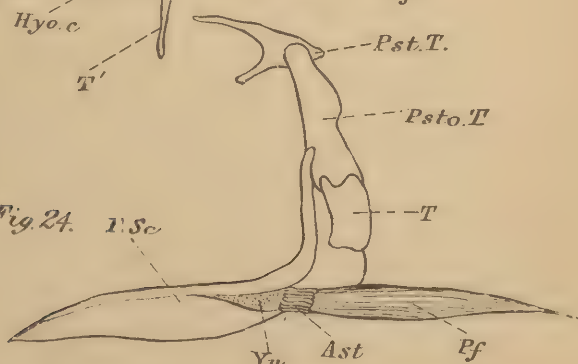


Fig. 24.

PLATE IX.

FIG. 25. The skeleton of the caudal extremity of *Amia*. The five small rods of bone, referred to by the letters *j.f.* are the continuation of the interneural spines. These have not been previously described, and were overlooked by Franque, consequently do not appear in his figure. Taken in connection with the free spines found over the anterior vertebræ of the column, these bones rather lead me to believe that in the early ancestors of *Amia* the fin was continuous, from base of cranium to include the tail. Life size from nature, by the author.

Fig. 25.

PLATE X.

FIG. 26. Left lateral view of the skeleton of *Amia calva*. Copied by Mr. H. L. Todd from Franque's figure and considerably reduced.

Fig. 26.

PLATE XI.

Fig. 27. Left lateral view of the skull of *Micropterus salmoides*, with the skeleton of other parts connected with it posteriorly. This figure is designed to show the relation of the bones, arranged *in situ*, of this part of the skeleton in a typical teleostean fish. Life size from nature, by the author, from his own dissections.

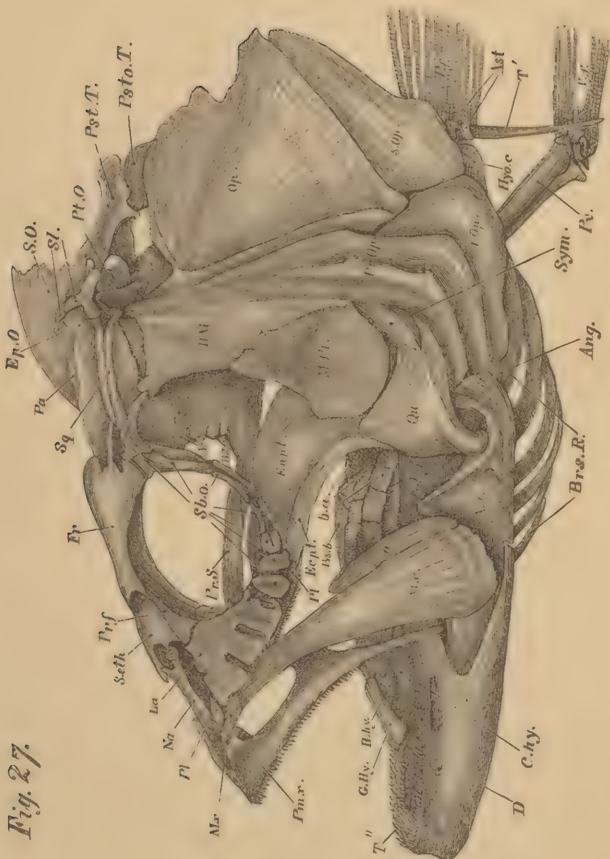

Ep.O
S.O.
Sl.
Pt.O
Pst.T.
Psto.T.
Ast
T'
Hyo.c
R.
Sym.
Ang.
Brs.R.
C.hy.
D
T''
G.Hy.
B.hy.
Pmx.
Mx
Pl
Na
La
S.eth
Prf
Fr.
Sq
Pa
Sb.o.
Pr.S.
Ecpt.
Qu

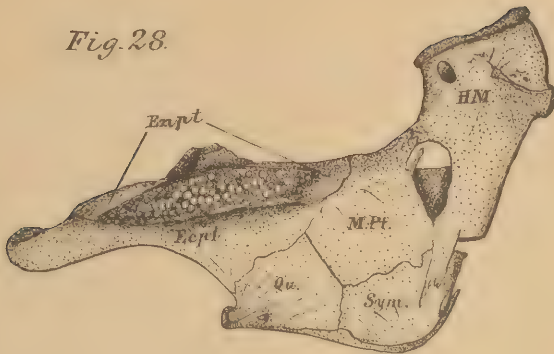
Fig. 27.

PLATE XII.

Fig. 28. Palatoquadrate arch, nearly complete, right side, inner aspect, of *Albula vulpes*. Same specimen as shown in Fig. 29. The area of teeth are seen just above the letters *Ecpt.* Life size. Drawn by the author from a specimen kindly lent him by Prof. Theodore Gill, from his private cabinet.

Fig. 29. Right lateral views of cranium of *Albula vulpes*, and the greater part of the palatoquadrate arch. Same specimen as figured in Fig. 28. Life size from nature, by the author, from the specimen in Professor Gill's cabinet.

Fig. 28.


Enpt.
HM.
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Ecpt.
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Sym.


S.O.
Pa
Sq
Fr
Prf
Eth.
Ep.O.
Op.O
c.v.
Os
Bs
Pr.O.
E.O.
Pr.S.
Na2
Vo
B.O.


HM.
Enpt.
M.Pt.
Ecpt.
Qu.
Sym.

Fig. 29.

PLATE XIII.

Fig. 30. Superior view of the cranium of *Albula vulpes.* From the same specimen of which the lateral view is shown in Fig. 29 of this paper. Life size from nature by the author.

Fig. 31. Inferior view of the cranium of *Albula vulpes.* The elliptical area of teeth are here seen upon the parasphenoid, *Pr. S.* Same specimen as in Fig. 30, from Professor Gill's collection. Life size, from nature, by the author.

Fig. 32. Inner aspect of opercular bones, hyoid, symplectic, and other elements of *Micropterus salmoides.* Left side. Designed to show the relations of these parts as found in a typical teleostean fish. Life size from nature; drawn by the author from his own dissections.

Fig. 30.

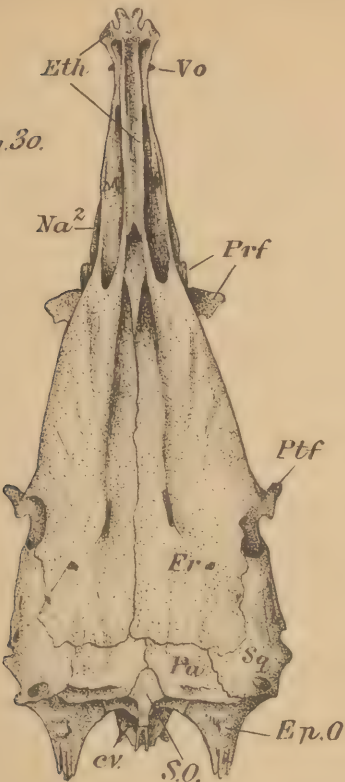


Fig. 31.

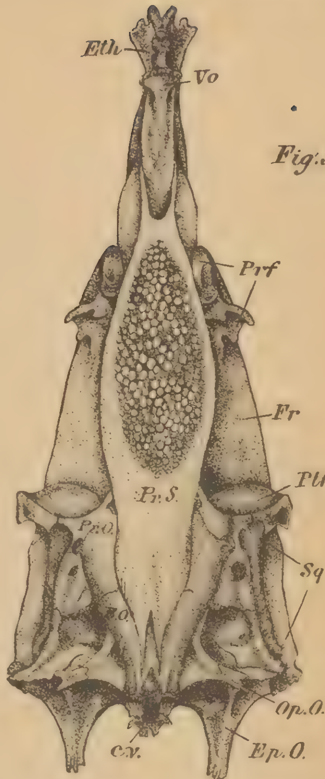


Fig. 32

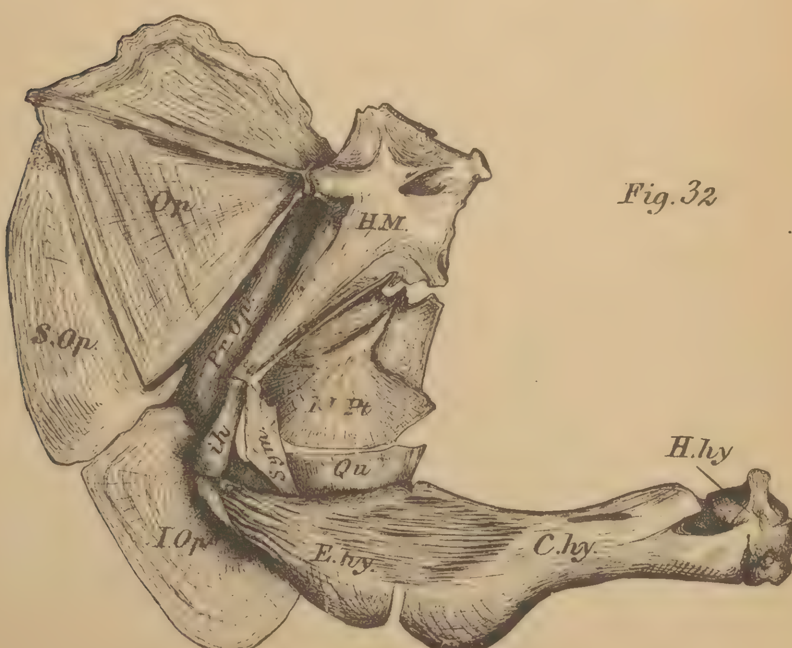


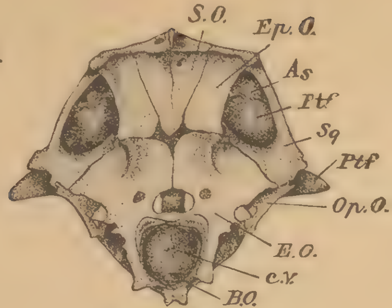
PLATE XIV.

FIG. 33. Posterior view of the cranium of *Megalops*. The first vertebra of the column is anchylosed with the basioccipital, and is referred to by the letters *c. v.* Life size.

FIG. 34. Right lateral view of the cranium of *Megalops*. Missing parts are seen from this aspect, as the parietals and basisphenoid. The normal position of this cranium would have the parasphenoid, *Pr. s*, in the horizontal plane, but it is represented this way to save space. This specimen is the same as seen in Fig. 33, and both were drawn by the author from a specimen kindly lent him by Professor Gill from his private cabinet.

FIG. 35. Outer aspect of part of shoulder girdle, and the pectoral fin of *Micropterus salmoides*. Life size. Drawn by the author from his own dissections.

Fig. 33.



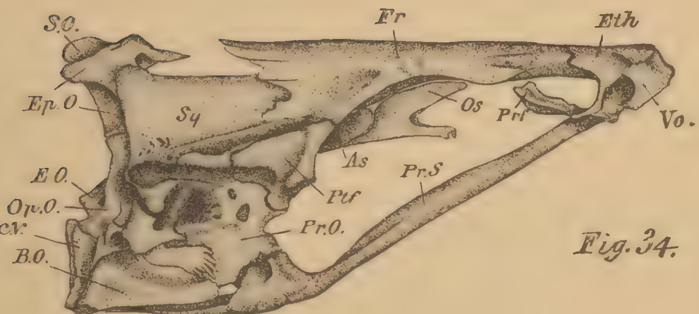
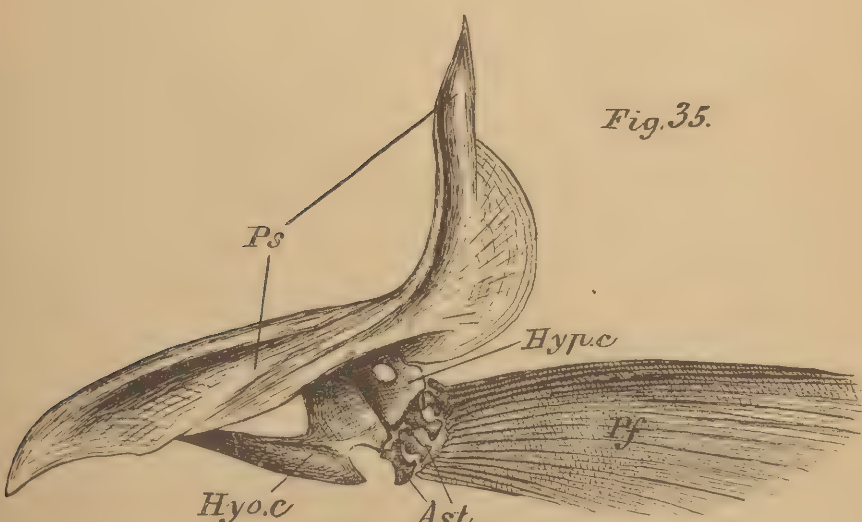


Fig. 34.

Fig. 35.



INDEX.

[NOTE.—The references are to page-figures in brackets.]

[EXTRACTED FROM THE ANNUAL REPORT OF THE COMMISSIONER OF FISH AND FISHERIES FOR 1883.]

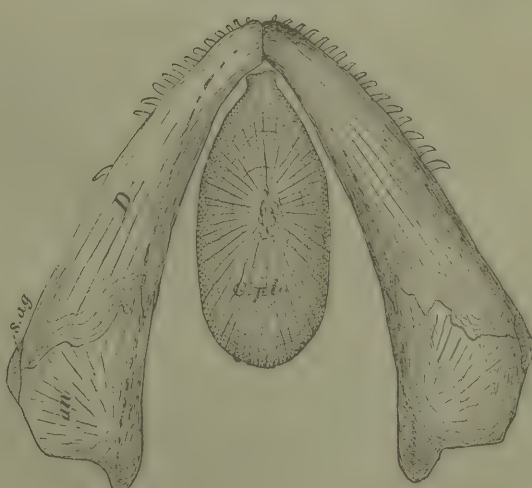
THE OSTEOLOGY OF AMIA CALVA,

INCLUDING

CERTAIN SPECIAL REFERENCES TO THE SKELETON OF TELEOSTEANS.

BY

R. W. SHUFELDT.



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